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THESIS

OPTIMIZING LOGISTICAL PLANNING FACTORS FOR FUEL RATE CONSUMPTION WITHIN THE FIFTH FLEET AREA OF RESPONSIBILITY

by

James A. Long

June 2011

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OPTIMIZING LOGISTICAL PLANNING FACTORS FOR FUEL RATE CONSUMPTION WITHIN THE FIFTH FLEET AREA OF RESPONSIBILITY

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The purpose of this thesis is to determine if the NWP 4-01.2 or the current "On Station" planning factors within RASP provide adequate estimates of fuel consumption within FIFTHFLT for seven classes of naval warships, or would fleet planners be better served with our newly computed "GeoRegion" planning factors. The analysis concludes the NWP and the "On Station" planning factors overestimate actual fuel consumption within the FIFTHFLT AOR. The "GeoRegion" planning factors proved to be more efficient and provided a more effective optimization of RAS deliveries. There were fewer RAS events using the new planning factors, reducing JP5 hits from 50 to 45 and DFM hits from 50 to 43. There was also a substantial decrease in the number of 4-hour periods the warships spent below 50% fuel capacity.

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LIST OF ACRONYMS AND ABBREVIATIONS

AG	Arabian Gulf
ANOVA	Analysis of Variance
AOR	Area of Responsibility
AS	Arabian Sea
boxplot	Box-and-Whisker Plot
CLF	Combat Logistical Force
CG	Cruiser, Guided Missile
CSG	Carrier Strike Group
CVN	Aircraft Carrier, Nuclear
DDG	Destroyer, Guided Missile
df	Degrees of Freedom
DFM	Distilled Fuel Marine
ESG	Expeditionary Strike Group
FFG	Frigate, Guided Missile
FIFTHFLT	FIFTH FLEET
GeoRegion	Geographical Region
GOA	Gulf of Aden
HOA	Horn of Africa
HSD	Honestly Significantly Different
IQR	Interquartile Range
JP5	Naval Aviation Fuel
LHD	Amphibious Assault Ship
LPD	Amphibious Transport Dock Ship
LSD	Amphibious Dock Landing Ship
MSC	Military Sealift Command
NPS	Naval Postgraduate School
NWP	Naval Warfare Publication
p-value	Probability Value
RAS	Replenishment-at-Sea
RASP	Replenishment-at-Sea-Planner

RS	Red Sea
SE	Standard Error
UNREP	Underway Replenishment

EXECUTIVE SUMMARY

The purpose of this thesis is to determine if there is a quantifiable difference in the logistics planning factors for fuel consumption contained in the Naval Warfare Publication (NWP) 4-01.2 "Sustainment-at-Sea," and observed data taken from operationally defined Geographical Regions (GeoRegions) in the FIFTH FLEET (FIFTHFLT) area of responsibility. More specifically, we analyze Navy ship fuel or Distilled Fuel Marine (DFM), and Naval Aviation Fuel, more commonly known as JP5, for seven U.S. Navy ship-classes. The insights we wish to acquire are twofold. The first to determine if the data collection for each ship class is statistically different from the fuel consumption "Sustainment" rates published in the NWP. This will determine if the NWP fuel consumption rates are useful for logistical planners at the strategic level within FIFTHFLT. The second is to determine if there is a statistical difference between in fuel consumption rates within each of the five identified sub-regions and compare those sub-regions to the "On Station" consumption rates in the Replenishment-at-sea-Planner (RASP). This reflects the intra-theater concerns of logistical planners at the operational level. In essence, the analysis will verify if the strategic and operational levels are in agreement, and provide more fidelity into the true fuel consumption rates within the FIFTHFLT AOR.

The data under analysis is drawn from daily OPREP-5 FEEDER reports submitted within the last two years by U.S. Navy combatant ships operating in the CETRAL COMMAND area of responsibility.

The model used to certify the analysis is RASP, which currently provides four options to assign a unit's operational status under the Current State, influencing fuel consumption: On Station, In Transit, At Anchor and Pier Side. RASP uses the NWP 4-01.2 (80% of Sustainment Consumption) as the "On Station" consumption rate planning factors for DFM in its optimization algorithm. Additionally, RASP uses the NWP 4-01.2 (Sustainment Consumption) as the "On Station" consumption rate planning factors for JP5 in its optimization algorithm. We model and investigate the effects of changing the

fuel burn rate for each class of ship, from using the current RASP generic "On Station" consumption category to the GeoRegion-specific fuel consumption in a controlled 28-day scenario using RASP.

The analysis concludes the NWP and the "On Station" planning factors currently used within RASP overestimate actual fuel consumption within the FIFTHFLT AOR. The "GeoRegion" planning factors proved to be more efficient and provided a more effective optimization of RAS deliveries. There were fewer RAS events using the new planning factors, reducing JP5 deliveries from 50 to 45 and DFM deliveries from 50 to 43. This will lead to substantial cost savings over an extended period of time. There was also a substantial decrease in the number of 4-hour periods the U.S. Navy warships spent below 50% fuel capacity during the 28-day scenario.

	"On Station" planning factors	"GeoRegion" planning factors
JP5 (4-hr periods spent below 50% fuel capacity)	107	3
DFM (4-hr periods spent below 50% fuel capacity)	136	71

I. INTRODUCTION

A. OBJECTIVES

The purpose of this thesis is to determine if there is a quantifiable difference in the logistics planning factors for fuel consumption contained in the Naval Warfare Publication (NWP) 4-01.2 "Sustainment-at-Sea," and observed data taken from operationally defined Geographical Regions (GeoRegions) in the FIFTH FLEET (FIFTHFLT) area of responsibility (Figure 1). More specifically, we analyze Navy ship fuel or Distilled Fuel Marine (DFM), and Naval Aviation Fuel, more commonly known as JP5, for each observed U.S. Navy ship-class to determine if the strategic and operational level of logistics planning factors are in agreement with the new GeoRegion planning factors and to model and investigate the effects of changing the fuel burn rate for each class of ship, from using the current RASP generic "On Station" consumption category to the GeoRegion-specific fuel consumption in a controlled 28-day scenario using RASP.

Figure 1. Map outlining the FIFTHFLT Area of Responsibility. (From www.deepseawaters.com)

B. OVERVIEW

There is a direct link between the development of accurate logistic planning factors and the success of any mission during wartime or peacetime operations. Many times in history, military campaigns have been cut short, if for nothing else, a lack of logistical foresight. We want to ensure that this does not occur in the planning factors used to calculate fuel requirements in execution of U.S. Navy operations afloat.

1. Planning Factors

Eccles (1950) stated, “All logistics planning is based on usage factors which are average figures computed in many various ways.” His usage factors have become known, in operational planning circles, as Logistics Planning Factors (LPFs). Formally defined in Joint Publication 1-02 (DoD Dictionary of Military and Associated Terms): “A properly selected multiplier used in planning to estimate the amount and type of effort involved in a contemplated operation. Planning factors often are expressed as rates, ratios, or lengths of time.”

Logistics planning factors are used by logisticians to estimate commodity requirements in support of military operations and unit deployments. Therefore, it is imperative to use the correct logistics planning factors for any logistical model. It ensures the approximation, optimization and solutions from any model provide feasible and useful results for the problem under analysis. If logistics planning factors are in place, they should be revisited periodically with analytical rigor to ensure useful results for future planning.

2. Underway Replenishment

Underway Replenishment (UNREP) is the broad term applied to all methods of transferring fuel, munitions, supplies, and personnel from one vessel to another while physically at-sea. During the last 50 years, this practice has been refined and is now accomplished by multi-commodity ships controlled and operated by Military Sealift Command (MSC). A robust UNREP capability enables combatant ships to maintain

continuous at-sea operations within an Area of Responsibility (AOR) for extended periods of time. This capability is particularly important when deployed to regions where there are no friendly ports with logistical support capabilities. UNREP also eliminates the transit time required to move from the ship's assigned operating area to the logistics support facility, the time required to return, as well as time spent entering, leaving and alongside the pier at a logistical hub. A significant goal of UNREP is maximizing operational availability of combatant units. This allows the sea-going military service to maintain full advantage of fleet assets and capabilities with minimal service interruptions.

There are two types of Combat Logistical Force (CLF) assets, shuttle ships and station ships. Station ships travel with and provide direct logistical support within the Carrier Strike Groups (CSGs). Shuttle ships provide logistics lift to station ships for simultaneous redistribution to ships within the CSG, and provide other naval forces directly from supply sources such as friendly ports. In a sense, their primary mission is to provide a steady stream of ammunition, spare parts, fuel and provisions (dry, refrigerated and frozen) to naval forces at sea.

C. PROBLEM DEFINITION

Military Sealift Command (MSC) actively seeks methods and means to minimize fuel consumed by shuttle ships. Given global economic uncertainty, fuel cost increases and constant pressures within government to reduce defense budgets; it has become imperative for MSC to increase the efficiency of operations while continuing to provide quality service to their combatant customer ships. Durkins (2011) states, "MSC field activities currently plan replenishment schedules manually with little or no quantitative analysis." They will continue to do so in the future, unless offered a better way to schedule replenishments that demonstrate a quantifiable improvement.

Reducing costs by improving scheduling is of the utmost priority for MSC. Plans are in place to show that RASP would improve overall performance of the scheduling. Durkins (2011) showed RASP would also provide a more fuel efficient execution plan and still ensure the customer combatant ships receive the necessary logistical support in a time frame that does not hamper or impair the mission of the warfighter. With fuel being

the biggest cost factor in the Fleet operating budget after personnel, an effective optimization plan would reduce MSC fuel costs associated with shuttle ship delivery. Improving the logistic planning factors will maximize the benefits of better scheduling practices achieved with RASP.

1. How the Problem Is Currently Solved

Logistic planning factors for petroleum consumption for each class of ship are currently defined in the Naval Warfare Publication (NWP) 4-01.2 "Sustainment-at-Sea." These numbers are used by logistics planners throughout the fleet and serve as a basis for several current analytic replenishment models. Previous research has shown current practices at Fleet planning activities is ad hoc at best, with little or no quantitative underpinnings (Durkins 2011).

2. How We Attempt to Solve the Problem

We seek to provide better logistic planning factors than those in the NWP 4-01.2 and in the current version of RASP for DFM/JP5 fuel consumption within the FIFTHFLT AOR. We use various methods of statistical and data analysis to establish the existence of a statistically significant mathematical difference between GeoRegions and that they vary from the current values contained in the NWP and RASP. These new planning factors better reflect actual fuel consumption by taking into account the mission set of the ship based on that unit's operating location. It is observable that a ship conducting anti-piracy operations will burn more fuel than a ship that is positioning for a show of force.

3. Markers for Success

The intention of this thesis to refine the maritime petroleum planning factors currently used and provide future studies and analytical work more precise forecasting parameters for FIFTHFLT fuel replenishment. Success was achieved by showing that the computed "GeoRegion" planning factors achieve a closer approximation to real-world data than the "On Station" planning factors currently used in RASP, and the existing NWP planning factors.

D. LITERATURE REVIEW

The study into logistic planning factors is not new. Previous studies into this subject include Sullivan (1995), who developed logistics planning factors for Humanitarian Assistance/Disaster Relief (HADR) and Rudko (2003), who estimated the logistic planning factors for the Littoral Combat Ship. These theses looked at the many logistical planning factors for a single mission type or a single class of ship, we will be investigating the maritime petroleum planning factors associated with seven different class of ships within the five sub-regions of FIFTHFLT, without consideration to a specific mission category.

Hallmann (2009) evaluated the benefits of using the Combat Logistics Force (CLF) planner to determine optimal routing of MSC ships. However, the model used by Hallmann does not take the Geographic Region (GeoRegion) of operation into consideration. We incorporate GeoRegion into RASP.

Durkins (2011) validated the use of RASP as an optimization tool for us to analyze the results of our data and substantiate the conclusion and recommendations of this thesis.

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II. METHODOLOGY

A. THE DATA

The data under analysis is drawn from daily OPREP-5 FEEDER reports submitted within the last two years by U.S. Navy combatant ships operating in the U.S. CENTRAL COMMAND area of responsibility. This operational report is the basic vehicle for deployed units to update Commander, U.S. Naval Forces Central Command (NAVCENT, dual-hatted as Commander, FIFTH FLEET) and subordinate NAVCENT Task Force Commanders on events of the previous 24-hour period while sharing items of interest with other ships. The report contains operational and logistics information, but what we are interested in is the fuel consumption of DFM and JP5. Each report states the exact number of barrels for each fuel type that is consumed on a daily basis.

The RASP model currently provides four options to assign a units operational status under the Current State, influencing fuel consumption: On Station, In Transit, At Anchor and Pier Side. RASP uses the NWP 4-01.2 (80% of Sustainment Consumption) as the "On Station" consumption rate planning factors for DFM in its optimization algorithm. Additionally, RASP uses the NWP 4-01.2 (Sustainment Consumption) as the "On Station" consumption rate planning factors for JP5 in its optimization algorithm. Sustainment Consumption figures used for comparative analysis taken from the NWP 4-01.2 are provided in Table 1.

Daily Petroleum Requirements					
Ship Type	POL Type	Capacity (bbls)	Pre-Assault Consumption (bbls/day)	Assault Consumption (bbls/day)	Sustainment Consumption (bbls/day)
CVN	DFM	-	-	-	-
	JP5	74,642	3,000	5,000	4,000
CG	DFM	15,032	1,429	757	757
	JP5	475	5	39	19
DDG-51	DFM	10,518	1,200	646	646
	JP5	475	5	34	19
FFG	DFM	4,286	Not Stated	304	304
	JP5	475	Not Stated	39	19
LHD	DFM	43,091	2,000	1,071	1,071
	JP5	14,452	72	759	512
LSD	DFM	19,150	725	346	346
	JP5	1,144	2	81	55
LPD-4	DFM	23,750	1,142	528	528
	JP5	6,700	17	324	221

Table 1. Table of current planning factors. (After DON 2007)

The NWP 4-01.2 does state as a caveat under the Daily Petroleum Requirements Table, "Planning factors provided in this NWP must be reviewed, assessed and adjusted as required to reflect the context of the mission and other factors that could alter consumption over time." This is especially true in FIFTHFLT, where there are a plethora of different mission types taking place within the sub-regional boundaries.

B. THE SHIPS

There are seven ship classes found in the data set. The ship classes were chosen as the most prominent ships to be found within a Carrier Strike Group (CSG) and/or an Expeditionary Strike Group (ESG). One ship type excluded from this study is the LPD17 SAN ANTONIO Class, since there was insufficient data available at this time for each of the defined GeoRegions under consideration.

1. NIMITZ Class Aircraft Carrier (CVN)

The Nimitz Class Carrier is the largest capital ship in the world with a displacement of approximately 97,000 tons. The ship's propulsion system is powered by a nuclear power plant, and therefore consumes no DFM fuel. The fuel customer on board the carrier is the attached air wing, comprised of 60–70 tactical jet aircraft and two dozen rotary wing aircraft, which consumes a large quantity of JP5 fuel.

2. TICONDEROGA Class Cruiser (CG)

Historically they were generally considered the smallest ships capable of independent operations, but with technology the difference in size and capability between the cruiser and the ARLEIGH BURKE Class Destroyer has all but disappeared. The ship's propulsion system consists of four General Electric LM2500 gas turbine engines, with 80,000 shaft horsepower (60,000 kW) which drives the DFM fuel consumption. Two Light Airborne Multipurpose System (LAMPS) SH-60B helicopters are the JP5 consumers.

3. ARLEIGH BURKE Class Destroyer (DDG)

These warships are fast moving ships that provide offensive/defensive multi-mission capabilities and escort services for CSGs, ESGs and UNREP ships. The propulsion system consists of four General Electric LM2500-30 gas turbines each generating 27,000 shaft HP coupled to two shafts, each driving a five-bladed reversible controllable pitch propeller which consumes the DFM fuel. The JP5 fuel is used by up to two SH-60 Seahawk helicopters carried aboard. It is important to note that DDGs with hull numbers between 51 and 78 have a flight deck, but no hanger bay and therefore do not deploy with organic flight assets.

4. OLIVER HAZARD PERRY Class Frigate (FFG)

These warships provide a multi-mission warfare capability and routinely used as escort ships for CSGs, ESGs, UNREP ships and merchant vessels. They often are found

carrying out independent operations such as anti-drug interdiction and maritime interception operations. The propulsion system is two General Electric LM2500-30 gas turbines generating 41,000 shaft HP through a single shaft and variable pitch propeller which utilizes DFM. The frigate can carry up to two LAMPS helicopters, which will consume the JP5 aviation fuel. It typically carries only one helicopter on board.

5. WASP Class Amphibious Assault Ship (LHD)

These warships provide an ability to bring Marines to ashore via two methods. The first is by helicopter, as there is a full complement of up to 42 helicopters on board which consume JP5 fuel. The other is by landing craft. They have the capability to carry Amphibious Assault Vehicles (AAVs), Landing Craft Air Cushion (LCAC) and Landing Craft Mechanized (LCM) in the well deck. The propulsion system is two boilers which powers two geared steam turbines with 70,000 shaft hp to two shafts using DFM fuel. These ships are capable of carrying an entire Marine Expeditionary Unit (MEU).

6. WHIDBEY ISLAND Class Dock Landing Ship (LSD)

These ships are primarily used for amphibious operations and carry up to 500 marines. The well deck is spacious and can accommodate up to four LCACs, which is the most of any U.S. naval ship. The propulsion system consists of four Colt Industries 16-cylinder diesel engines, which produce 33,000 shaft hp to the two shafts. There is no hanger bay, but the ships typically have one helicopter aboard.

7. AUSTIN Class Landing Transport Dock Ship (LPD)

These ships are capable of delivery up to 900 marines for amphibious operations. They are also used as auxiliary airlift platform. They include two landing spots on the aft flight deck, one on the starboard side and the other on the port. The propulsion system consists of two boilers which powers two steam turbines with 24,000 shaft hp to two shafts. They are capable of carrying up to six CH-46 Sea Knight helicopters.

C. THE GEOGRAPHICAL AREAS

The five operational areas examined are the Red Sea (RS), the Gulf of Aden (GOA), the Horn of Africa (HOA), the Arabian Sea (AS) and the Arabian Gulf (AG), as depicted in Figure 2. These areas were determined by the reported locations of ships on the OPREP-5 data and subject matter expertise.

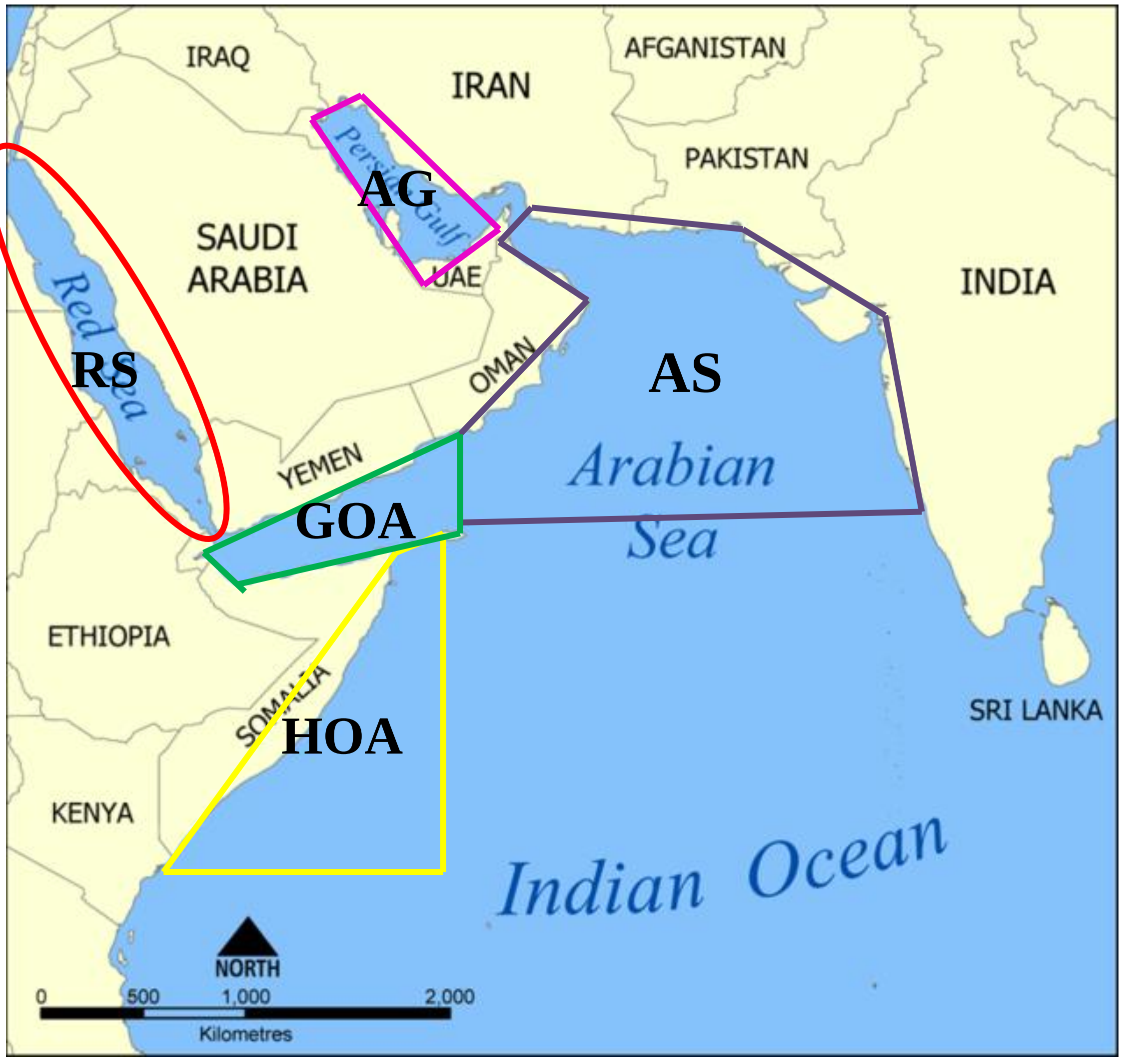

Figure 2. Layout of the five sub-regions of FIFTH FLEET. (After www.deepseawaters.com)

D. THE APPROACH

The data analysis is executed using a statistical software package called "R." R is an open-source computing package available and provides the ability to perform robust statistical analysis. This tool is used to analyze the data and draw our conclusions from those results.

There are several steps in the analysis. First, we graph the data and develop a visual sense of what the data is telling us. Next, we determine the summary statistics, which include the mean, median, the range, the interquartile range, the standard deviation, the variance and the confidence interval of each sample.

In the following formulas, *n* represents the numeric sample size.

1. Analysis of Variance

Next, we performed an Analysis of Variance (ANOVA) on the sample means of the sub-regions for each class of ship with 95% confidence factor. An ANOVA allows us to compare all groups with just one statistical test while keeping the confidence level at 95%. We will perform this test to see if there is a mathematically significant difference in the fuel burn rates within the sub-regions or the differences are due to random sampling variation. The null hypothesis (H_0) is the population mean for each sub-region is equal for all groups, and that the observed differences in sample means are due to random sampling variation. The alternative hypothesis (H_a) is the observed differences between sample means are due to actual differences in the population means.

There are two methods of ANOVA and they fall into two categories, parametric and nonparametric. The non-parametric ANOVA is typically used when the populations are not normally distributed, or the data is severely skewed. The parametric ANOVA is the most simplistic, but there are certain assumptions we need to make.

- random, independent sampling of the *n* populations
- populations for each sample are normally distributed
- equal variance within the *n* populations

We will verify the assumption of normality using a normal probability plot.

Another common assumption used in one-way ANOVA is based on the assumption that all of the groups share a common, but unknown, variance. In practice, this assumption rarely holds true, which leads to problems controlling the Type I error rate. Type I error is the probability of incorrectly rejecting the null hypothesis (concluding the samples are significantly different when they are not). When the samples have different variances, there is a greater likelihood that the test will reach an incorrect conclusion. In this case, we transform the data to provide a better fit to the basic assumption. To transform the data, we apply a mathematical function to each data set of log base 10, and then use those numbers in the statistical test.

2. Pair-Wise Comparison

When an ANOVA test is statistically significant, indicating that at least one of the sample means is different from the others, the next step in the analysis is to determine which samples are statistically different. For a parametric ANOVA that has proven to be statistically significant, we use Tukey's Honestly Significantly Different (HSD) test. Tukey's HSD ensures the comparison is maintained at the alpha level of the test and preserves the integrity of the type I error against inflation.

3. T-Test

Hypothesis testing is a way of systematically quantifying how certain you are of the result of a statistical experiment. This allows us to determine if our sample subset's mean is really different from the population or the difference is due to sampling error associated with pure chance. The t-test is a type of hypothesis test, and two t-tests are performed in the analysis.

The first test involves testing the entire set of data points within a GeoRegion to the existing NWP 4-01.2, and determine if there is statistical difference between the two using a 95% confidence factor. The test statistic we will use is the *t* distribution. This will determine if the NWP is adequate for use as holistic planning tool within FIFTHFLT.

$$t = \frac{X - \mu_0}{s/\sqrt{n}}$$

The second test compares the groups the Tukey HSD test considered statistically different from the ANOVA, to the fuel burn rate currently used by RASP using a 98% confidence factor.

E. THE MODEL

We made recommendations for changing the planning parameters within RASP based on the findings of the analysis, and ran the optimization model in a controlled 28 day scenario. The control data presents the actual fuel consumption for 14 operationally employed U.S. Navy warships in the FIFTHFLT AOR. It is our desire to show that a change in the planning factors to more accurately reflect actual fuel consumption within Fifth Fleet, will result in a more precise solution from RASP to assist field activities in UNREP scheduling. Additionally, we seek any reduction in discretionary UNREP activity (those events generated by RASP) as an indicator of improved efficiency of CLF employment, realizable through more accurate measurements of commodity requirements.

III. ANALYSIS

A. INTRODUCTION

The insights we wish to acquire are twofold. The first is to determine if the data collection for each ship class is statistically different from the fuel consumption “Sustainment” rates published in the NWP. This will determine if the NWP fuel consumption rates are useful for logistical planners at the strategic level within FIFTHFLT. The second is to determine if there is a statistical difference between in fuel consumption rates within each of the five identified sub-regions and compare those sub-regions to the “On Station” consumption rates in RASP. This reflects the intra-theater concerns of logistical planners at the operational level. In essence, the analysis will verify if the strategic and operational levels are in agreement, and provide more fidelity into the true fuel consumption rates within the FIFTHFLT AOR.

We examine and interpret the data for DFM and JP5 for each of seven ship classes. The analytical method will be thoroughly demonstrated for the DDG ship class in detail showing all figures and tables used to logically formulate a conclusion. It is worth mentioning that the selection of the DDG class is an arbitrary choice, as any ship-class would suffice. Summary statistics for other ship classes are located in Appendix A and the R code used to obtain results of this analysis is in Appendix B.

As helicopters were not observed to fly every day, JP5 consumption data differs from DFM consumption data. JP5 consumption reports of less than three bbls per day were classified as “no fly days.” It is our belief that reports of two barrels or less consumed were due to maintenance and not operations. No fly day observations were removed from the sample population. Each data point in the remaining portion of the data set was multiplied by one minus the ratio of no fly days to total days for each respective sub-region. This enabled the analysis to proceed in a parametric manner with data that represented the entire population.

B. DDG

1. DFM

The first step in this analysis is to determine the population mean, which is given to us from the NWP, a consumption rate of 646 bbls per day (refer to Table 1). A 95% confidence level hypothesis test is performed to determine if our sample (the collective data points from RS, GOA, HOA, AS and AG) could have come from a population (NWP) whose mean is 646. Table 2 shows it is statistically unlikely, and indicates this sample did not come from a population whose mean is 646. The probability value (p-value) is the probability of getting a value of the test statistic as extreme as or more extreme than that observed by chance alone. The confidence interval (C.I.) indicates a range of values where we expect the population mean to reside. This hypothesis test demonstrates logistical planners at the strategic level are grossly overestimating fuel consumption for DDGs as a whole within FIFTHFLT.

Hypothesis Test: DDG (DFM) vs. NWP (DFM)	
Hypothesis: True mean of the sample is equal to 646. Sample mean (DDG): 482.4	95 percent C.I.: 455.0 - 510.0 P-value < 2.2e-16

Table 2. Hypothesis test for DGG (DFM). Results: Reject the hypothesis. DDG data is not equal to the NWP.

Next, we will examine the data at the operational level. Notice in Figure 3, the mean and confidence interval for sub-region AS are significantly different and represent a contrast to the other sub-regions.

DFM	RS	GOA	HOA	AS	AG
Mean	423.25	459.60	419.10	711.07	395.03
Median	410.5	457.5	401	692	410.5
Range	207-743	307-807	229-909	489-983	221-591
S.D.	132.34	99.87	135.22	142.57	98.78
Variance	17514.05	9973.21	18285.40	20327.10	9756.65
C.I.	374.2 - 472.3	423.9 - 495.3	370.7 - 467.5	660.0 - 762.1	359.7 - 430.4

Figure 3. Summary Statistics for DDG DFM fuel consumption. This chart shows the AS sub-region's confidence interval and mean are significantly greater than the other sub-regions.

Figure 4 shows the box-and-whisker plots (boxplots) are arranged left to right along the horizontal axis. Each boxplot portrays statistical features for the RS, GOA, HOA, AS and AG sub-regions. The box height indicates the span of data lying between the 25th and 75th percentiles, also referred to as the interquartile range. The horizontal line dividing the box marks the median value for each group. The plot shows RS, GOA, HOA and AG appear to have similar medians, which are much smaller than that of the AS sub-region. The AS sub-region appears to have greater variability than the other sub-regions. There are only a few obvious outliers in RS, GOA and HOA, which suggests the data is likely derived from a normal distribution. The boxplots imply there is a difference between AS and the other four sub-regions.

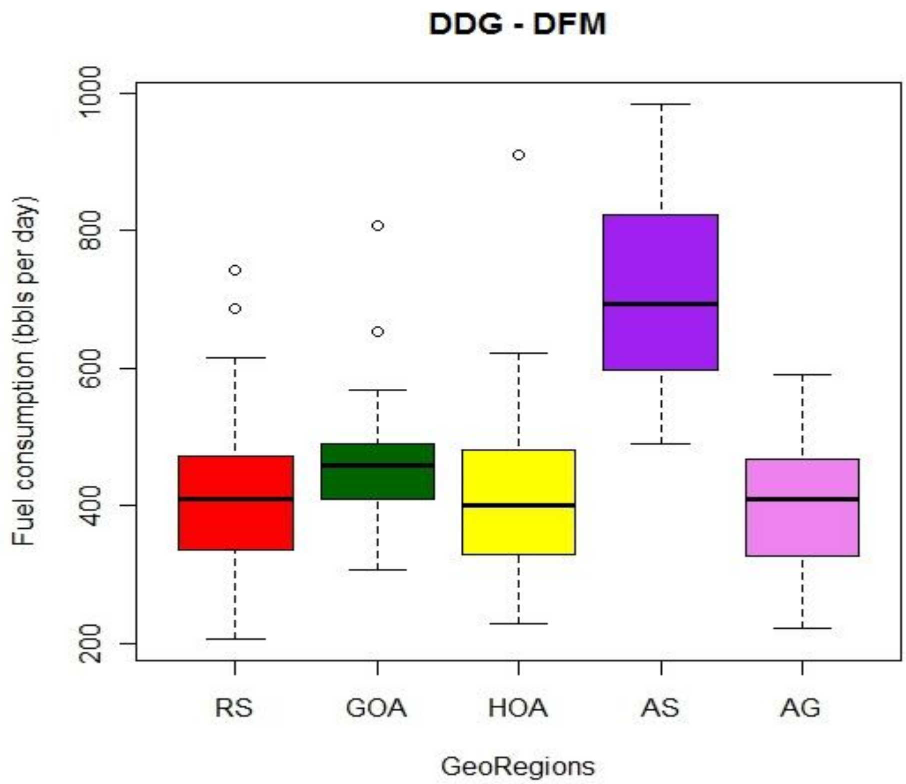

Figure 4. Side by side boxplots signifying DFM fuel consumption. Sub-region AS shows that its median fuel consumption rate is significantly greater than the other four sub-regions.

The next step requires verification that the data follows the normal distribution. An assumption of parametric statistics is that the data is normally distributed. Normality plots indicate if the data originated from a normal distribution. Data that originates from a normal distribution will form a 45-degree line commencing in the bottom left hand corner of the plot and finishing at the upper right hand corner. Figure 5 shows the normality plots, supporting that the data is reasonably normal for RS, AS and AG.

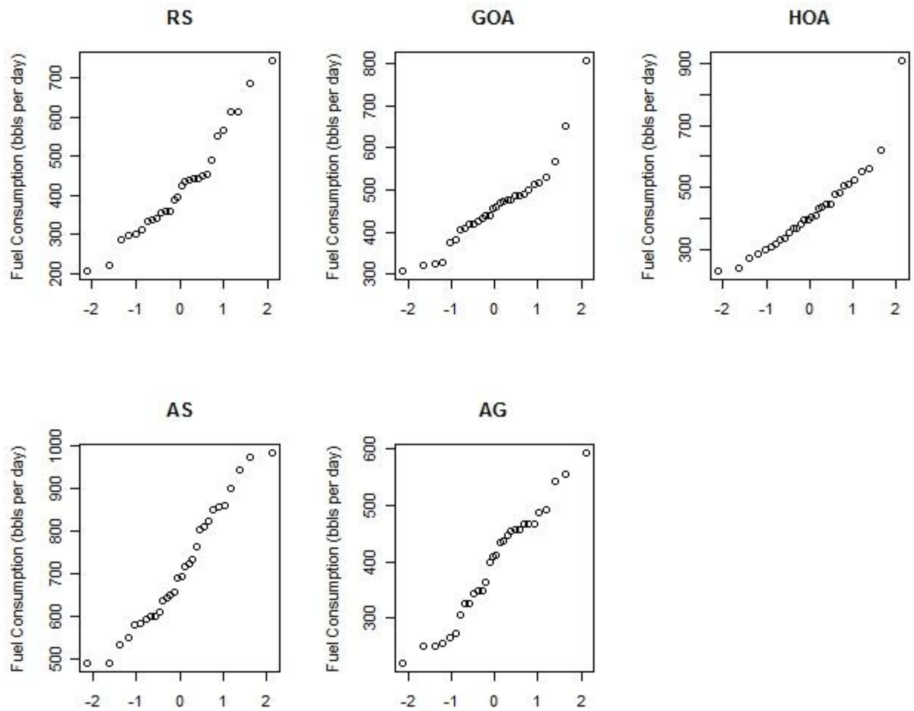

Figure 5. Normality plots for DFM fuel consumption.

A base-10 logarithmic transformation was applied to the data to more closely meet the assumptions of the statistical inference procedure to be applied. Transformations are often applied to compensate for nonlinearity and outliers, which in turn, makes the data appear more normal. Figure 6 shows that a logarithmic transformation of the data reduced the influence of the outliers. The data now appears to be reasonably normal for all sub-regions. This allows us to continue the analysis under the parametric process using the logarithmic fuel consumption rate.

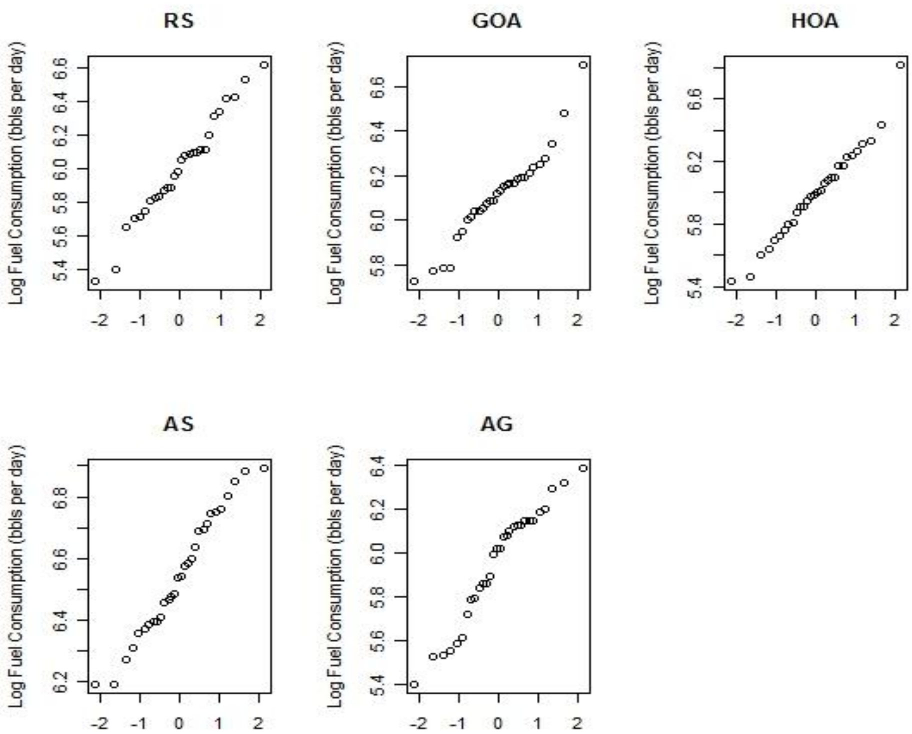

Figure 6. Normality plots for DFM logarithmic fuel consumption.

Next, an analysis of variance (ANOVA) was performed to analyze the data and determine if there is a significant statistical difference between one or more of the means. Table 3 shows that the p-value (highlighted in yellow) is considerably smaller than .05. A p-value lower than the alpha parameter (in this case .05) indicates a significant statistical difference in one or more of the means. Alpha is derived from one minus the confidence level (1-.95=.05).

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GeoRegion	4	7.2564	1.81410	27.105	2.2e-16
Residuals	143	9.5709	0.06693		

Table 3. ANOVA results for DFM. The p-value is very small and indicates there is a significant difference between one or more of the means.

A pair-wise comparison test was performed to determine which mean or means are different using Tukey's HSD test. When Tukey's HSD test is performed, we determined that a sub-region will be separated for hypothesis testing against the RASP data if that sub-region is statistically different from two or more of the other sub-regions. Figure 7 confirms our suspicion that the AS sub-region is statistically different from the other sub-regions. To interpret the plot, examine the interval of the line for each pair. If the interval crosses 0.0, then there is no statistical difference in the means, however if it does not, then we can confirm that the means of that pair are indeed different.

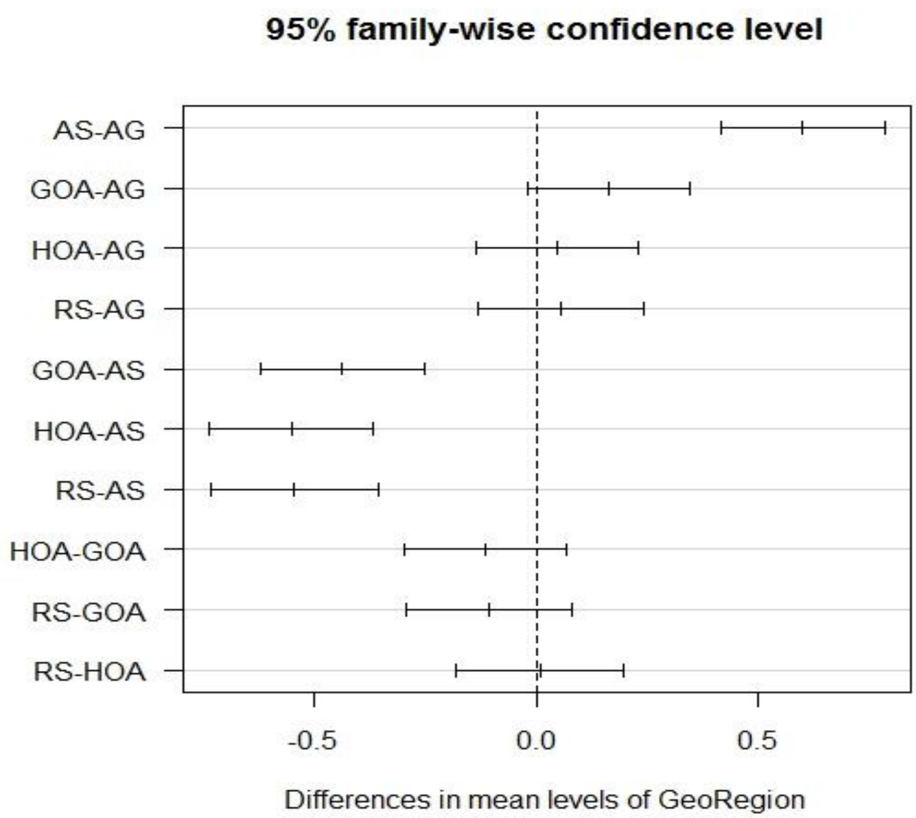

Figure 7. Tukey's HSD pair-wise comparison for DFM fuel consumption at a 95% confidence level. The plot confirms that sub-region AS is statistically different from the other sub-regions.

Given the results thus far, two subsets were created from the five sub-regions. The first subset contains the data points from RS, GOA, HOA and AG. We will pool these sub-regions together, since the ANOVA indicates that they are statistically the

same. The second subset will contain only the AS sub-region. These data sets will be compared independently to the fuel consumption rate currently employed in RASP. The hypothesis test between RASP and the two data sets was tested at a 98% confidence level to reduce the possibility of a type I error. A confidence level of 98% vice 95% will significantly reduce the possibility of encountering a type I error, since we will be performing a multitude of hypothesis tests throughout this portion of the analysis.

Notice in Tables 4 and 5, the p-values are extremely low and reveal both subsets differ from RASP. This exemplifies the need to modify the "On Station" planning factors within RASP. We propose using the ceiling of the sample mean for the applicable sub-regions within RASP for the purposed "GeoRegion" planning factors.

Hypothesis Test: AS (DFM) vs. RASP (DFM)	
Hypothesis: True mean of the sample is equal to 605.6 Sample mean (AS): 711.1	98 percent C.I.: 647.0 - 775.2 P-value = 0.0003476

Table 4. Hypothesis test for AS (DFM). Results: Reject the hypothesis and change the RASP value. Proposed value is 712 bbls per day.

Hypothesis Test: RS/HOA/GOA/AG (DFM) vs. RASP (DFM)	
Hypothesis: True mean of the sample is equal to 605.6 Sample mean (RS/HOA/GOA/AG): 424.3	98 percent C.I.: 398.6 - 450.0 P-value < 2.2e-16

Table 5. Hypothesis test for RS/HOA/GOA/AG (DFM). Results: Reject the hypothesis and change the RASP value. Proposed value is 425 bbls per day.

2. JP5 Fuel

JP5 data was analyzed and found to contain an inordinate amount of days where there was no fuel expended. After further investigation, many of those days with no fuel expenditure were attributed to DDGs with hull numbers between 51 and 78, which have

no organic flight assets, and were therefore removed from the sample population. An additional removal from the operational data context: all other observations with fewer than 3 bbls of JP5 consumed on any given day were classified as "no fly days."

The population mean for JP5 is 19 bbls per day (refer to Table 1). A 95% confidence level hypothesis test is performed to determine if our sample (the collective data points from RS, GOA, HOA, AS and AG) could have come from a population whose mean is 19. Table 6 shows it is statistically unlikely this sample came from a population whose mean is 19, since the p-value is less than .05, also the C.I. indicates 19 does not fall within the range of values where we expect the population mean to reside. This hypothesis test demonstrates logistical planners referencing the NWP are incorrectly forecasting JP5 fuel consumption for DDGs within FIFTHFLT.

Hypothesis Test: DDG (JP5) vs. NWP (JP5)	
Hypothesis: True mean of the sample is equal to 19 Sample mean (DDG): 15.8	95 percent C.I.: 13.2 - 18.4 P-value = 0.01831

Table 6. Hypothesis test for DDG (JP5). Results: Reject the hypothesis. DDG data is not equal to the NWP.

Now we must examine the JP5 fuel consumption at the operational level. Notice in Figure 8, the mean and confidence interval for sub-region AG are lower than the other sub-regions.

JP5	RS	GOA	HOA	AS	AG
Mean	19.73	13.56	14.00	14.72	8.80
Median	16.8	16.3125	11	12.75862069	7.2
Range	3.73 - 43.87	2.81 - 24.19	9.00 - 22.00	2.76 - 51.72	2.70 - 24.30
S.D.	12.60	7.52	7.00	10.43	6.69
Variance	158.78	56.59	49.00	108.76	44.71
C.I.	15.07 - 24.40	10.87 - 16.25	11.50 - 16.50	10.99 - 18.46	6.41 - 11.19

Figure 8. Summary Statistics for DDG JP5 fuel consumption. This chart shows the AG sub-region's confidence interval and mean are less than the other sub-regions.

The boxplots in Figure 9 show the medians differ to some degree within the sub-regions. The RS sub-region appears to have more variability. There seems to be some overlap of the IQRs in most groups. The boxplots imply there may be a difference between AG and some of the other sub-regions, as the IQR has slight or no overlap with the other groups.

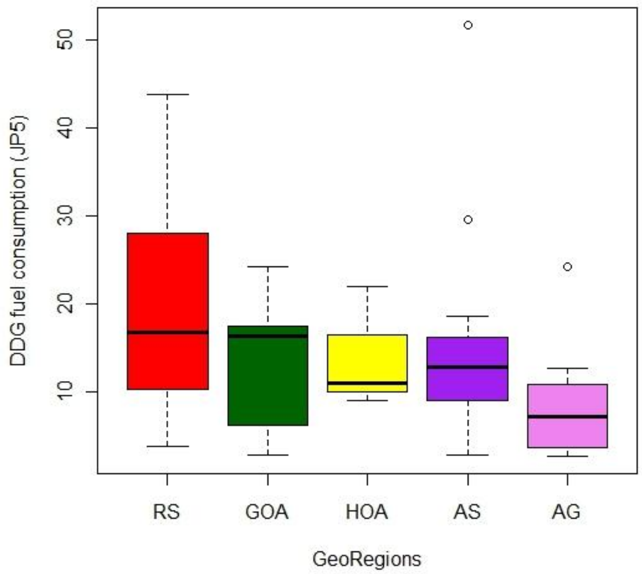

Figure 9. Side by side boxplots signifying JP5 fuel consumption. Sub-region AG shows that the median fuel consumption rate is relatively smaller than the other sub-regions.

Figure 10 shows the normality plots for JP5 fuel consumption. The plots confirm the data is reasonably normal for RS, GOA and HOA. It appears as if the outliers are influencing the normality of AS and AG. A logarithmic transformation will be applied in an effort to nullify the effects of the outliers.

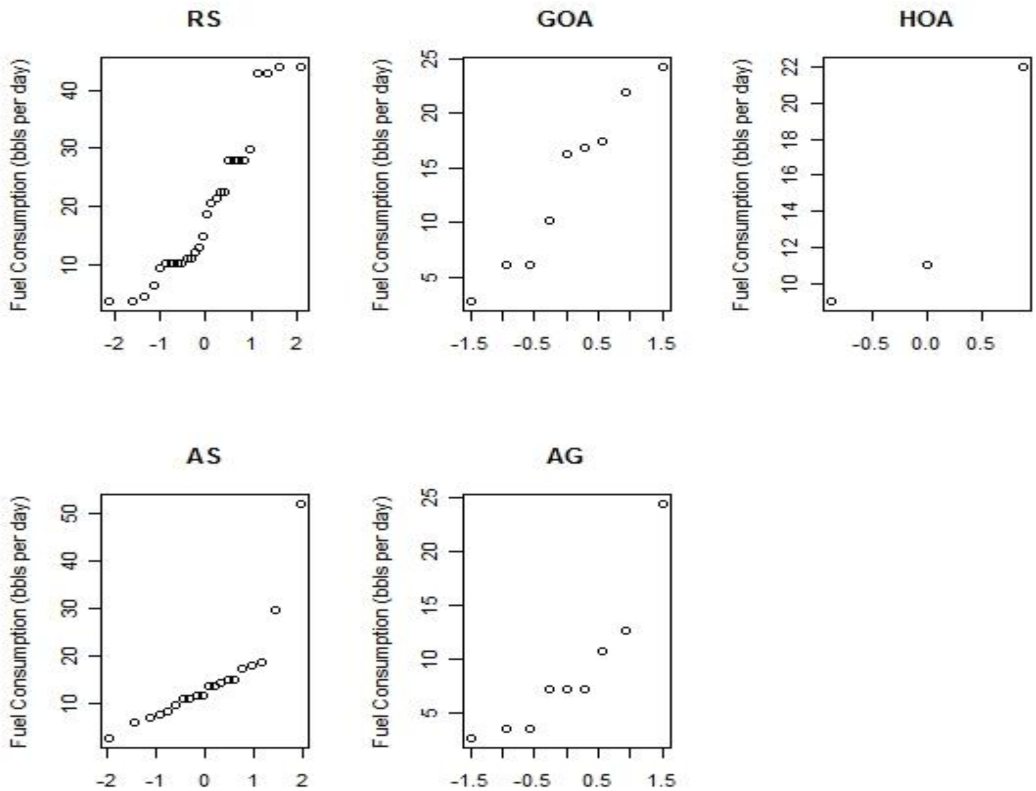

Figure 10. Normality plots for JP5 fuel consumption.

Figure 11 shows that a logarithmic transformation of the data reduced the influence of the outliers. The transformed data now appears to be reasonably normal for all sub-regions. This allows us to continue the analysis under the parametric process using the logarithmic fuel consumption rate for the ANOVA.

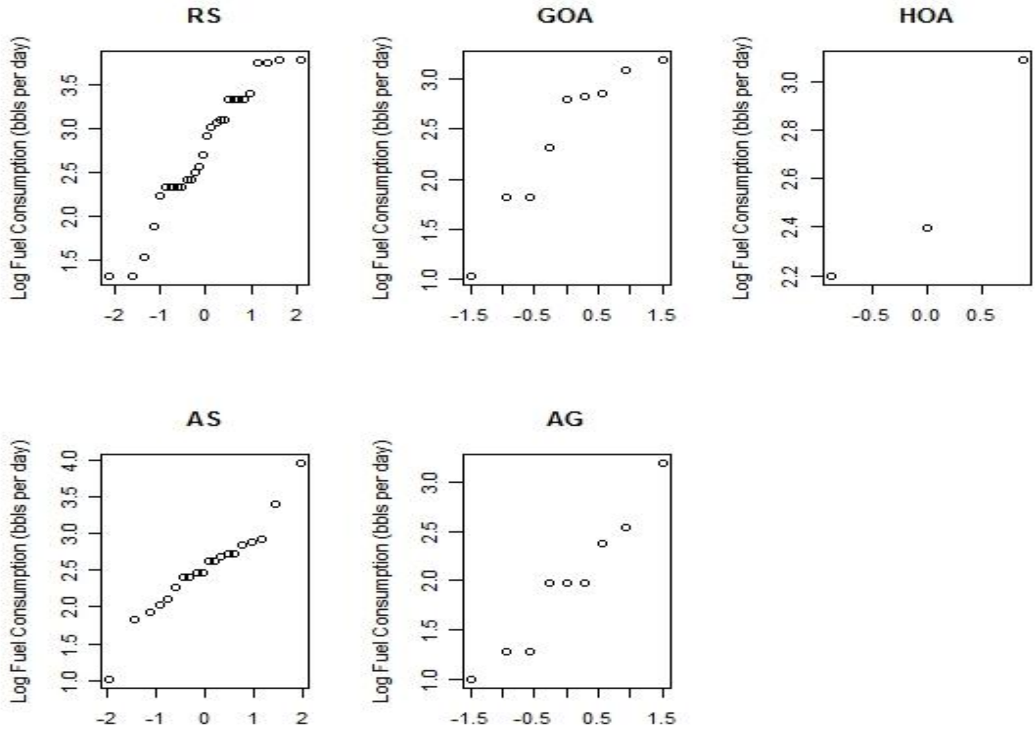

Figure 11. Normality plots for JP5 logarithmic fuel consumption.

An analysis of variance was performed, and Table 7 shows that the p-value (highlighted in yellow) is slightly larger than .05, which indicates there is no significant difference in one or more of the means.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GeoRegion	4	4.5817	1.14542	2.49	0.05187
Residuals	64	29.4405	0.46001		

Table 7. ANOVA results for JP5. The p-value is larger than .05 and indicates there is no significant difference between one or more of the means.

The data for all sub-regions will be pooled, since there is no statistical difference among them, to create one subset, and compared to the fuel consumption rate in RASP. The comparison will be completed using a 98% confidence level hypothesis test. Table 8 shows the p-value is greater than .02, and a p-value greater than .02 indicates the

difference between the sample mean and population mean are due to nothing more than sampling error. This demonstrates there is no need to modify the "On Station" planning factors for JP5 fuel consumption within RASP for the DDG ship-class. The analysis shows the GeoRegion planning factors are significantly different from the NWP, but not from RASP.

Hypothesis Test: RS/HOA/GOA/AG (JP5) vs. RASP (JP5)	
Hypothesis: True mean of the sample is equal to 17 Sample mean (RS/HOA/GOA/AG): 15.8	95 percent C.I.: 13.2 - 18.4 P-value = 0.3681

Table 8. Hypothesis test for RS/HOA/GOA/AG (JP5). Results: Do not reject the hypothesis. There is no significant difference between the DDG data and RASP.

C. FFG

It is important to note, that no data was available for AG sub-region for the FFG-class. Therefore, we will only examine the RS, GOA, HOA and AS sub-regions.

1. DFM

The population mean for DFM is 304 bbls per day (refer to Table 1). A 95% confidence level hypothesis test is performed to determine if our sample (the collective data points from RS, GOA, HOA, and AS) could have come from a population whose mean is 304. Table 9 shows it is statistically unlikely this sample came from a population whose mean is 304, since the p-value is significantly less than .05, also the C.I. indicates 304 does not fall within the range of values where we expect the population mean to reside. This hypothesis test demonstrates logistics planners referencing the NWP are incorrectly forecasting DFM fuel consumption for FFGs within FIFTHFLT.

Hypothesis Test: FFG (DFM) vs. NWP (DFM)	
Hypothesis: True mean of the sample is equal to 304 Sample mean (FFG): 274.4	95 percent C.I.: 252.3 - 296.4 P-value = 0.008928

Table 9. Hypothesis test for FFG (DFM). Results: Reject the hypothesis. FFG data is not equal to the NWP.

Now we must examine the DFM fuel consumption at the operational level. Figure 12 shows considerable variability in three of the four regions. The medians of HOA and AS are larger than RS and GOA. There is apparent overlap of the IQRs within all regions. Looking at the boxplots, it appears there may be a possible difference between the regions RS/GOA and AS based on the median.

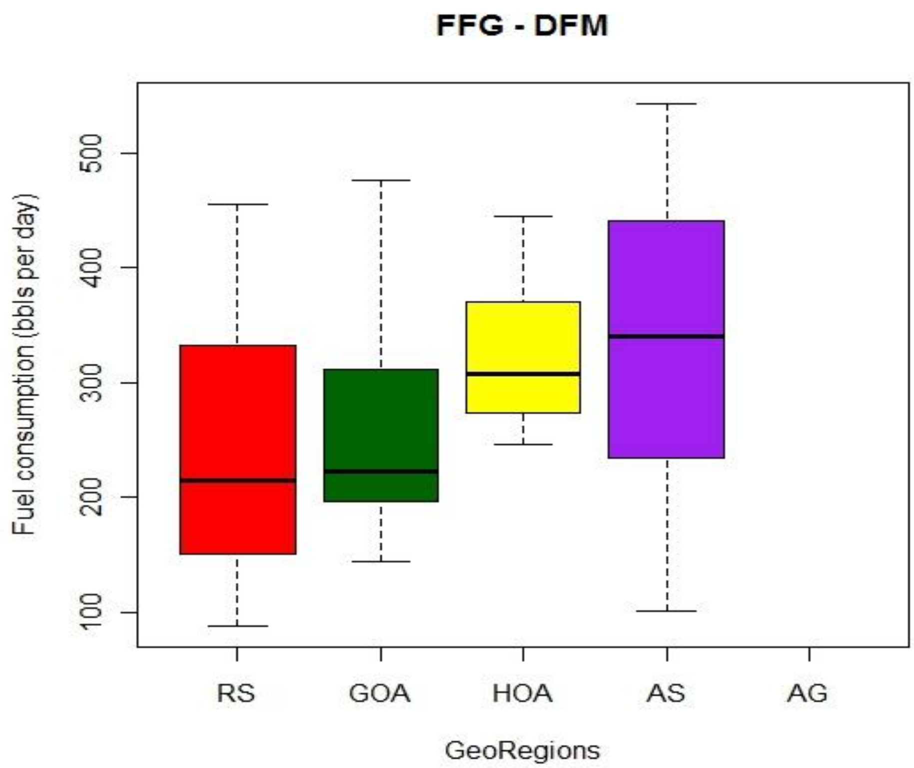

Figure 12. Side by side boxplots signifying DFM fuel consumption. The plots show RS and GOA have a relatively smaller median in comparison to the other two sub-regions.

A logarithmic transformation was applied to this data prior to completing the ANOVA. Table 4 presents the ANOVA results, indicating a very small p-value (highlighted in yellow). This demonstrates a significant difference between one or more of the means. A pair-wise comparison is required to determine which means are significantly different.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GeoRegion	3	2.0045	0.66818	4.9046	0.003406
Residuals	86	11.7162	0.13623		

Table 10. ANOVA results for DFM. The p-value is very small and indicates there is a significant difference between one or more of the means.

Tukey's HSD test was performed, and Figure 13 indicates the RS-AS pair differs, but neither differs from any other sub-region. Given this result, we will create one pooled subset of data points from all four sub-regions to compare to RASP.

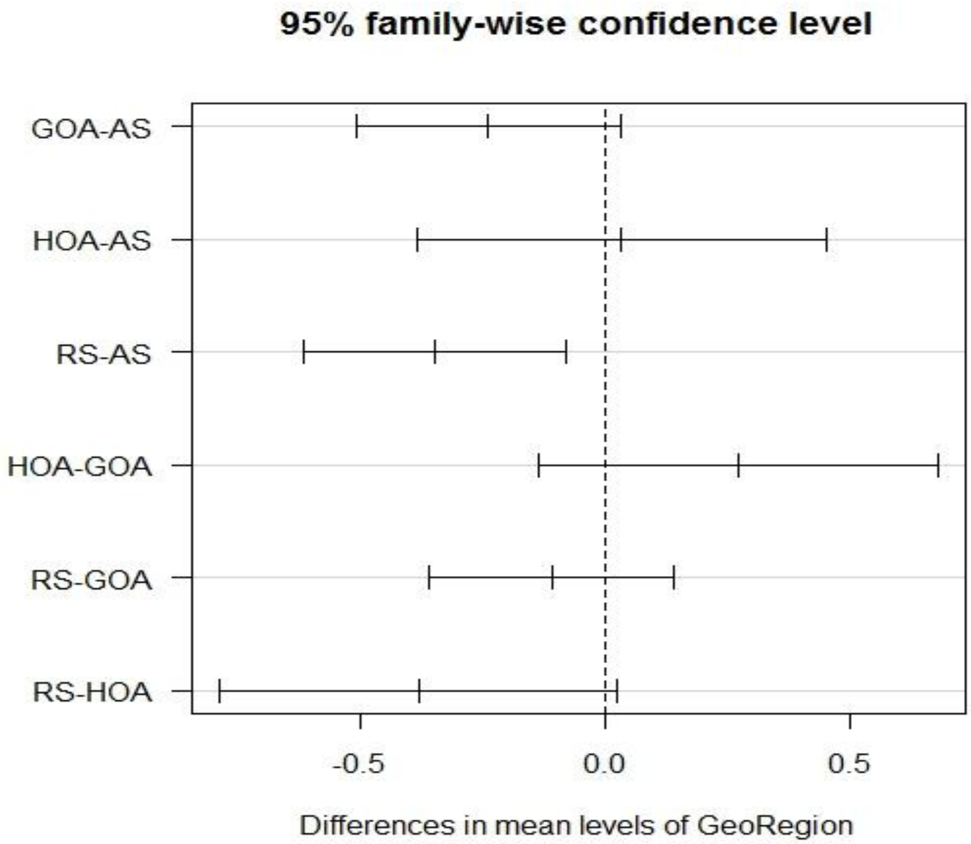

Figure 13. Tukey's HSD pair-wise comparison for DFM fuel consumption at a 95% confidence level. The plot indicates the RS-AS pair is statistically different.

A 98% confidence level hypothesis test was performed and Table 11 shows the p-value is less than .02. This demonstrates the need to modify the "On Station" planning factors for DFM fuel consumption within RASP for the FFG ship-class. The analysis shows the GeoRegion planning factors are significantly different from both the NWP and RASP.

Hypothesis Test: RS/HOA/GOA/AS (DFM) vs. RASP (DFM)	
Hypothesis: True mean of the sample is equal to 243.2 Sample mean (RS/HOA/GOA/AS): 274.4	98 percent C.I.: 248.1 - 300.6 P-value = 0.006058

Table 11. Hypothesis test for RS/HOA/GOA/AS (DFM). Results: Reject the hypothesis and change the RASP value. Proposed value is 275 bbls per day.

2. JP5 Fuel

The population mean for JP5 is 19 bbls per day (refer to Table 1). A hypothesis test is performed to determine if our sample (the collective data points from RS, GOA, HOA, and AS) could have come from a population whose mean is 19. Table 12 shows it is statistically likely this sample came from a population whose mean is 19, since the p-value is significantly higher than .05, also the C.I. indicates 19 does fall within the range of values where we expect the population mean to reside. This hypothesis test demonstrates logistics planners referencing the NWP are correctly forecasting DFM fuel consumption for CGs within FIFTHFLT.

Hypothesis Test: FFG (JP5) vs. NWP (JP5)	
Hypothesis: True mean of the sample is equal to 19 Sample mean (FFG): 17.7423	95 percent C.I.: 14.1 - 21.4 P-value = 0.4894

Table 12. Hypothesis test for CG (DFM). Results: Reject the hypothesis. CG data is not equal to the NWP.

Now we must examine the DFM fuel consumption at the operational level. Figure 14 shows considerable variability in the GOA sub-region, as well as little variability in the AS sub-region. The IQR of AS appears to not overlap the IQRs of RS and GOA. The boxplot implies there may be a difference between AS and the other sub-regions or GOA and the other sub-regions.

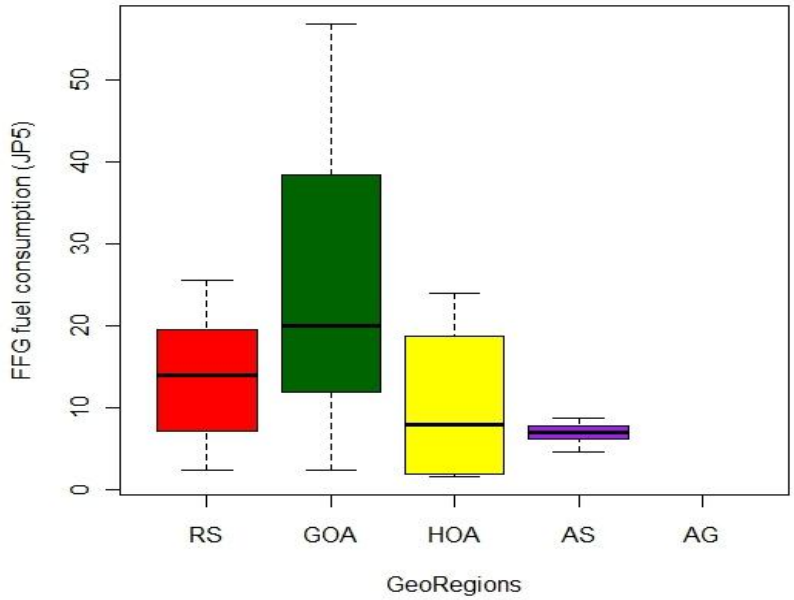

Figure 14. Side by side boxplots signifying JP5 fuel consumption. The plots show the GOA region has large variability.

Table 13 presents the ANOVA, indicating a very small p-value (highlighted in yellow). This demonstrates a significant difference between one or more of the means. A pair-wise comparison is required to determine which means are significantly different.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GeoRegion	3	2804.8	934.93	6.314	0.0009467
Residuals	54	7995.9	148.07		

Table 13. ANOVA results for JP5. The p-value is very small and indicates there is a significant difference between one or more of the means.

Tukey's HSD test was performed, and Figure 15 indicates that the GOA-AS pair and the RS-GOA pair differ. Given this result, two subsets were created to compare to RASP using a 98% confidence level hypothesis test. The first subset consists of the data

points from the GOA sub-region, and the second one consists of the pooled data points from the RS, HOA and AS sub-regions.

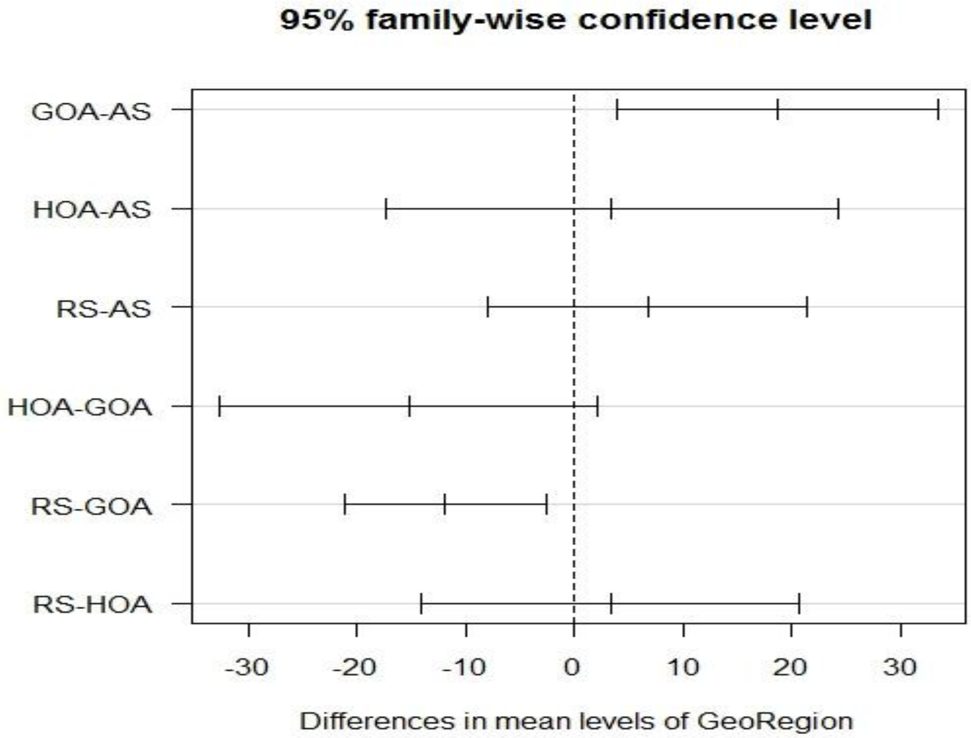

Figure 15. Tukey's HSD pair-wise comparison for JP5 fuel consumption at a 95% confidence level. The plot indicates the GOA sub-region is statistically different from more than one other sub-region.

A 98% confidence level hypothesis test was performed and Tables 14 and 15 show the p-values are less than .02. This demonstrates the need to modify the "On Station" planning factors for JP5 fuel consumption within RASP for the FFG ship-class. The analysis shows the GeoRegion planning factors are significantly different from RASP, but align well to the NWP.

Hypothesis Test: GOA (JP5) vs. RASP (JP5)	
Hypothesis: True mean of the sample is equal to 17 Sample mean (GOA): 25.7	98 percent C.I.: 17.02 - 34.3 P-value = 0.01981

Table 14. Hypothesis test for GOA (JP5). Results: Reject the hypothesis and change the RASP value. Proposed value is 26 bbls per day.

Hypothesis Test: RS/HOA/AS (JP5) vs. RASP (JP5)	
Hypothesis: True mean of the sample is equal to 17 Sample mean (RS/HOA/AS): 12.2	98 percent C.I.: 9.2 - 15.1 P-value = 0.0003011

Table 15. Hypothesis test for RS/HOA/AS (JP5). Results: Reject the hypothesis and change the RASP value. Proposed value is 13 bbls per day.

D. CVN

During the past two years (the time frame in which the samples were obtained), CVN operational tasking only occurred in the AS sub-region. The CVN has data points in the other sub-regions, but those occurred while in a transient status, and are not applicable to this study. We will compare this sample directly to RASP with a 98% confidence level hypothesis test to evaluate if the RASP “On Station” planning factors for CVN require modification.

A 98% confidence level hypothesis test was performed and Table 16 shows the p-value is less than .02. This demonstrates the need to modify the “On Station” planning factors for JP5 fuel consumption within RASP for the CVN ship-class. The analysis shows the GeoRegion planning factors are significantly different from RASP. We can infer from this test that the GeoRegion planning factors are also different from the NWP, since a 95% confidence level with the same data would cast a more restrictive C.I.

Hypothesis Test: AS (JP5) vs. RASP (JP5)	
Hypothesis: True mean of the sample is equal to 4000 Sample mean (AS): 2135.8	98 percent C.I.: 1761.5 - 2510.1 P-value = 5.336e-13

Table 16. Hypothesis test for AS (JP5). Results: Reject the hypothesis and change the RASP value. Proposed value is 2136 bbls per day.

E. CG

1. DFM

The population mean for DFM is 757 bbls per day (refer to Table 1). A 95% confidence level hypothesis test is performed to determine if our sample (the collective data points from RS, GOA, HOA, AS, and AG) could have come from a population whose mean is 757. Table 17 shows it is statistically unlikely this sample came from a population whose mean is 757, since the p-value is significantly less than .05, also the C.I. indicates 757 does not fall within the range of values where we expect the population mean to reside. This hypothesis test demonstrates logistics planners referencing the NWP are incorrectly forecasting DFM fuel consumption for CGs within FIFTHFLT.

Hypothesis Test: CG (DFM) vs. NWP (DFM)	
Hypothesis: True mean of the sample is equal to 757 Sample mean (CG): 580.9	95 percent C.I.: 547.9 - 613.9 P-value < 2.2e-16

Table 17. Hypothesis test for CG (DFM). Results: Reject the hypothesis. CG data is not equal to the NWP.

Now we must examine the DFM fuel consumption at the operational level. The boxplots in Figure 16 show the median of the AG sub-region is substantially lower than the other areas. The AS and GOA sub-regions appear to have larger variability than the

other sub-regions. There are only a few obvious outliers in RS, HOA and AG which suggests the data in normally distributed. The boxplots imply the AG sub-region may differ from the other sub-regions.

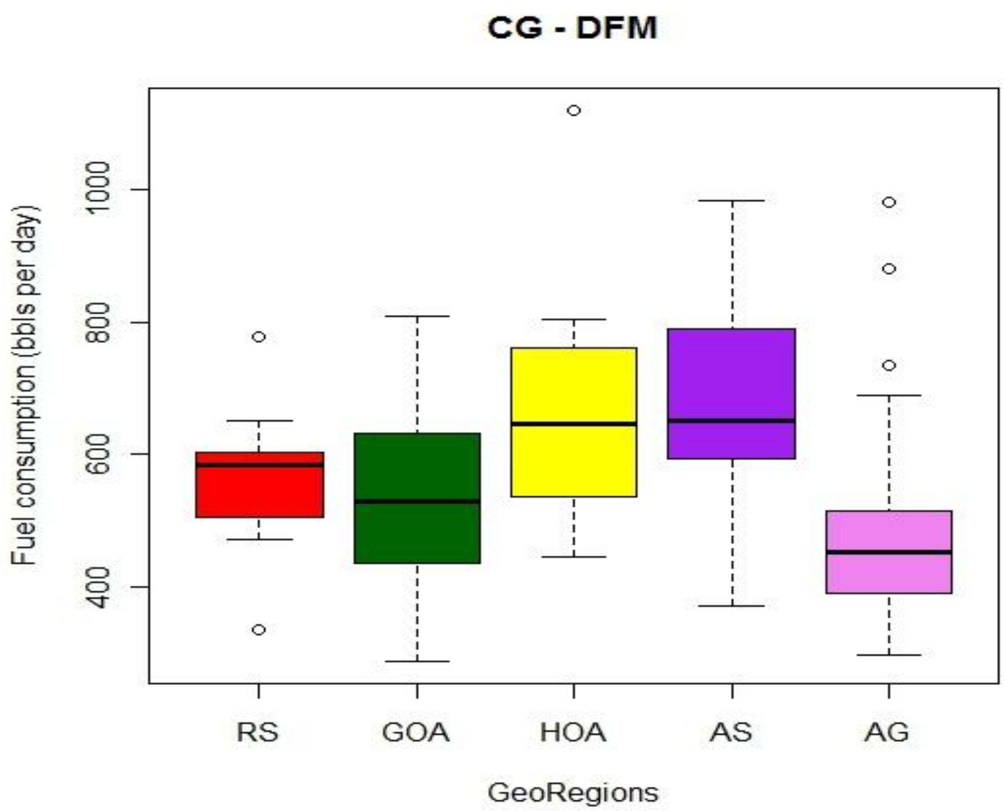

Figure 16. Side by side boxplots signifying DFM fuel consumption. Sub-region AG shows that the median fuel consumption rate is comparatively smaller than that of the other sub-regions.

A logarithmic transformation was applied to this data prior to completing the ANOVA. Table 18 presents the ANOVA results, indicating an extremely small p-value (highlighted in yellow). This demonstrates a significant difference between one or more of the means. A pair-wise comparison will be required to determine which means are significantly different.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GeoRegion	4	2.0377	0.50943	7.4754	2.540e-05
Residuals	102	6.9511	0.06815		

Table 18. ANOVA results for DFM. The p-value is very small and indicates there is a significant difference between one or more of the means.

Tukey's HSD test was performed, and Figure 17 indicates there is a significant difference in the AS-AG, HOA-AG and GOA-AS pairs.

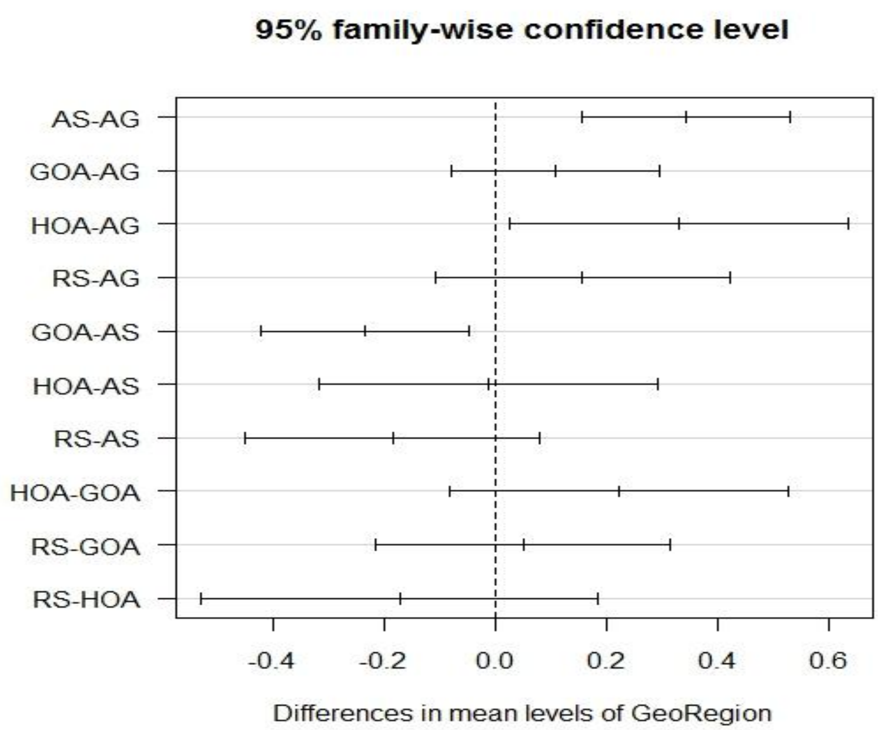

Figure 17. Tukey's HSD pair-wise comparison for DFM fuel consumption at a 95% confidence level. The plot indicates the AS-AG, HOA-AG and GOA-AS pairs are statistically different.

The AS and AG sub-regions differ from more than one sub-region, so we will partition these two areas into their own individual subsets. RS, HOA and GOA will be combined to create a third subset.

A 98% confidence level hypothesis test was performed and Tables 19 and 20 show the p-values are less than .02. This demonstrates the need to modify the "On Station" planning factors for DFM fuel consumption within RASP for the FFG ship-class. Table 21 shows the p-value is greater than .02, and a p-value greater than .02 indicates the difference between the sample mean and population mean are due to nothing more than sampling error. This demonstrates there is no need to modify the "On Station" planning factors for DFM fuel consumption within RASP for these sub-regions. The analysis shows the GeoRegion planning factors are significantly different from the NWP. The analysis also shows the GeoRegion planning factors are significantly different from RASP in two of the five sub-regions.

Hypothesis Test: AG (DFM) vs. RASP (DFM)	
Hypothesis: True mean of the sample is equal to 605.6 Sample mean (AG): 493.1	98 percent C.I.: 422.7 - 563.6 P-value = 0.0004818

Table 19. Hypothesis test for AG (DFM). Results: Reject the hypothesis and change the RASP value. Proposed value is 494 bbls per day.

Hypothesis Test: AS (DFM) vs. RASP (DFM)	
Hypothesis: True mean of the sample is equal to 605.6 Sample mean (AG): 684.9	98 percent C.I.: 613.3 - 756.5 P-value = 0.01073

Table 20. Hypothesis test for AS (DFM). Results: Reject the hypothesis and change the RASP value. Proposed value is 685 bbls per day.

Hypothesis Test: RS/HOA/GOA (DFM) vs. RASP (DFM)	
Hypothesis: True mean of the sample is equal to 605.6 Sample mean (AG): 570.6	98 percent C.I.: 515.6 - 625.6 P-value = 0.1314

Table 21. Hypothesis test for RS/HOA/GOA (DFM). Results: Do not reject the hypothesis. There is no significant difference between the CG data and RASP.

2. JP5 Fuel

The population mean for JP5 is 19 bbls per day (refer to Table 1). A 95% confidence level hypothesis test is performed to determine if our sample (the collective data points from RS, GOA, HOA, AS and AG) could have come from a population whose mean is 19. Table 22 shows it is statistically unlikely this sample came from a population whose mean is 19, since the p-value is significantly less than .05, also the C.I. indicates 19 does not fall within the range of values where we expect the population mean to reside. This hypothesis test demonstrates logistics planners referencing the NWP are incorrectly forecasting DFM fuel consumption for CGs within FIFTHFLT.

Hypothesis Test: CG (JP5) vs. NWP (JP5)	
Hypothesis: True mean of the sample is equal to 19 Sample mean (CG): 23.8	95 percent C.I.: 21.1 - 26.5 P-value = 0.0007269

Table 22. Hypothesis test for CG (JP5). Results: Reject the hypothesis. CG data is not equal to the NWP.

Now we must examine the DFM fuel consumption at the operational level. The boxplots in Figure 18 show the median of the HOA sub-region is lower than the other areas. The GOA sub-region appears to have larger variability. The boxplots imply the HOA sub-region may differ from the other sub-regions.

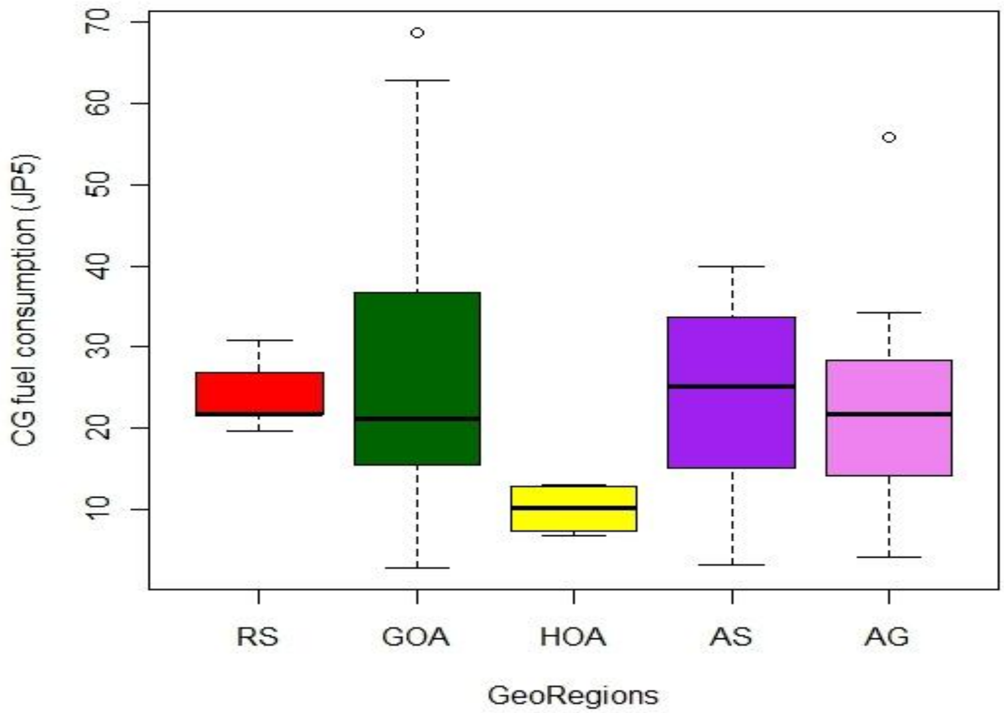

Figure 18. Side by side boxplots signifying JP5 fuel consumption. Sub-region HOA shows that the median fuel consumption rate is comparatively smaller than that of the other sub-regions.

Table 23 presents the ANOVA results, indicating a large p-value (highlighted in yellow). This demonstrates there is no significant difference between one or more of the means. The data for all sub-regions will be pooled, since there is no statistical difference among them, to create one subset. This subset will be compared to the fuel consumption rate in RASP. The comparison will be completed using a 98% confidence level hypothesis test.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GeoRegion	4	1134.2	283.56	1.7896	0.1385
Residuals	84	13309.5	158.45		

Table 23. ANOVA results for JP5. The p-value is larger than .05 and indicates there is no significant difference between one or more of the means.

A 98% confidence level hypothesis test was performed and Table 24 shows the p-values is less than .02. This demonstrates the need to modify the "On Station" planning factors for JP5 fuel consumption within RASP for the CG ship-class. The analysis shows the GeoRegion planning factors are significantly different from both the NWP and RASP.

Hypothesis Test: RS/HOA/GOA/AS/AG (JP5) vs. RASP (JP5)	
Hypothesis: True mean of the sample is equal to 17 Sample mean (RS/HOA/GOA/AS/AG): 23.8	98 percent C.I.: 20.5 - 27.0 P-value = 3.0205e-06

Table 24. Hypothesis test for RS/HOA/GOA/AS/AG (JP5). Results: Reject the hypothesis and change the RASP value. Proposed value is 24 bbls per day.

F. LHD

It is important to note, that no data was available for the AS sub-region. Therefore, we will only examine the RS, GOA, HOA and AG sub-regions.

1. DFM

The population mean for DFM is 1,071 bbls per day (refer to Table 1). A 95% confidence level hypothesis test is performed to determine if our sample (the collective data points from RS, GOA, HOA, and AG) could have come from a population whose mean is 1,071. Table 25 shows it is statistically unlikely this sample came from a population whose mean is 1,071, since the p-value is significantly less than .05, also the C.I. indicates 1,071 does not fall within the range of values where we expect the population mean to reside. This hypothesis test demonstrates logistics planners referencing the NWP are incorrectly forecasting DFM fuel consumption for LHDs within FIFTHFLT.

Hypothesis Test: LHD (DFM) vs. NWP (DFM)	
Hypothesis: True mean of the sample is equal to 1071 Sample mean (LHD): 847.5	98 percent C.I.: 788.1 - 907.0 P-value = 9.444e-11

Table 25. Hypothesis test for LHD (DFM). Results: Reject the hypothesis. LHD data is not equal to the NWP.

Now we must examine the DFM fuel consumption at the operational level. The boxplots in Figure 19 show the median of HOA is much greater than the other three areas. HOA also shows greater variability. Few of the IQRs have overlap. The boxplots imply there may be a difference in multiple sub-regions.

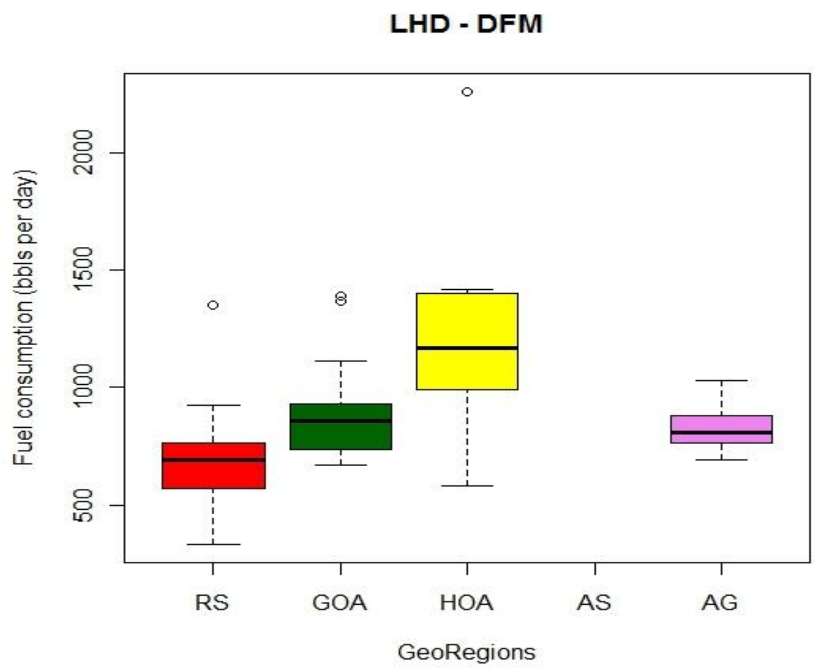

Figure 19. Side by side boxplots signifying DFM fuel consumption. Sub-region HOA shows that the median fuel consumption rate is greater than other sub-regions.

A logarithmic transformation was applied to this data prior to completing the ANOVA. Table 26 presents the ANOVA results, indicating an extremely small p-value

(highlighted in yellow). This demonstrates a significant difference between one or more of the means. A pair-wise comparison will be required to determine which means are significantly different.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GeoRegion	3	2.1520	0.71733	13.607	3.549e-07
Residuals	75	3.9539	0.05272		

Table 26. ANOVA results for DFM. The p-value is very small and indicates there is a significant difference between one or more of the means.

Tukey's HSD test was performed, and Figure 20 indicates there is a significant difference in the most pairs.

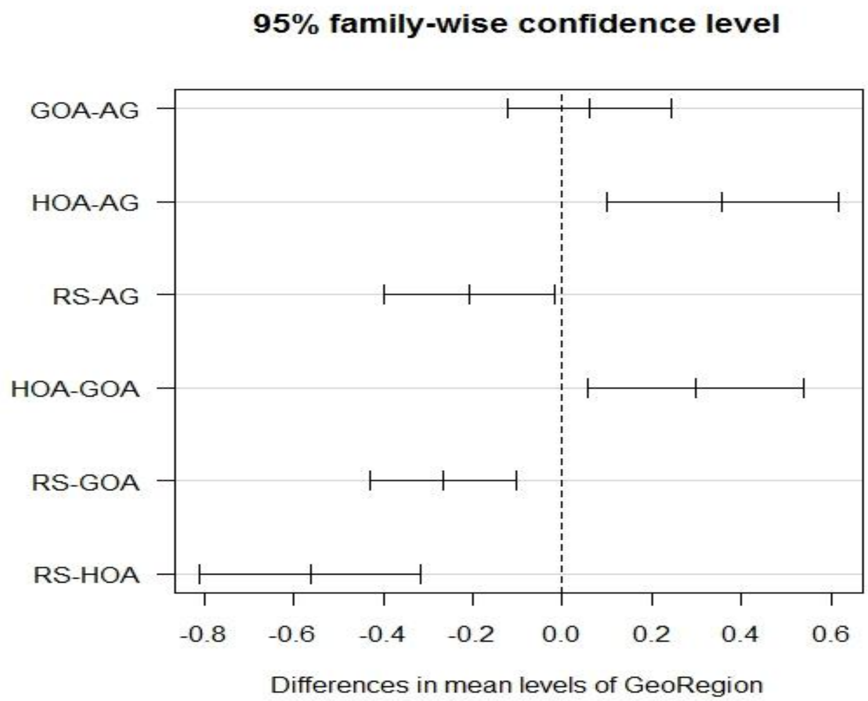

Figure 20. Tukey's HSD pair-wise comparison for DFM fuel consumption at a 95% confidence level. The plot indicates most pairs are statistically different.

All sub-regions differ from more than one other sub-region, so each sub-region will become its own subset. We will now compare the four subsets to the RASP model through hypothesis testing.

A hypothesis test was performed and Table 27 shows the p-value is less than .02. This demonstrates the need to modify the "On Station" planning factors for DFM fuel consumption within RASP for the FFG ship-class. Tables 28-30 show the p-values are greater than .02, and a p-value greater than .02 indicates the difference between the sample mean and population mean are due to nothing more than sampling error. This demonstrates there is no need to modify the "On Station" planning factors for DFM fuel consumption within RASP for these sub-regions. The analysis shows the GeoRegion planning factors are significantly different from the NWP. The analysis also shows the GeoRegion planning factors are significantly different from RASP in one of the four sub-regions.

Hypothesis Test: RS (DFM) vs. RASP (DFM)	
Hypothesis: True mean of the sample is equal to 856.8 Sample mean (RS): 689.0	98 percent C.I.: 589.1 - 788.9 P-value = 0.0003437

Table 27. Hypothesis test for RS (DFM). Results: Reject the hypothesis and change the RASP value. Proposed value is 689 bbls per day.

Hypothesis Test: GOA (DFM) vs. RASP (DFM)	
Hypothesis: True mean of the sample is equal to 856.8 Sample mean (GOA): 882.3	98 percent C.I.: 803.3 - 961.3 P-value = 0.4327

Table 28. Hypothesis test for GOA (DFM). Results: Do not reject the hypothesis. There is no significant difference between the GOA data and RASP.

Hypothesis Test: HOA (DFM) vs. RASP (DFM)	
Hypothesis: True mean of the sample is equal to 856.8 Sample mean (HOA): 1246.25	98 percent C.I.: 728.3 - 1764.2 P-value = 0.05883

Table 29. Hypothesis test for HOA (DFM). Results: Do not reject the hypothesis. There is no significant difference between the HOA data and RASP.

Hypothesis Test: AG (DFM) vs. RASP (DFM)	
Hypothesis: True mean of the sample is equal to 856.8 Sample mean (AG): 822.3	98 percent C.I.: 766.6 - 878.0 P-value = 0.1293

Table 30. Hypothesis test for AG (DFM). Results: Do not reject the hypothesis. There is no significant difference between the AG data and RASP.

2. JP5 Fuel

The population mean for JP5 is 512 bbls per day (refer to Table 1). A hypothesis test is performed to determine if our sample (the collective data points from RS, GOA, HOA, and AG) could have come from a population whose mean is 512. Table 31 shows it is statistically unlikely this sample came from a population whose mean is 512, since the p-value is significantly less than .05, also the C.I. indicates 512 does not fall within the range of values where we expect the population mean to reside. This hypothesis test demonstrates logistics planners referencing the NWP are incorrectly forecasting JP5 fuel consumption for LHDs within FIFTHFLT.

Hypothesis Test: LHD (JP5) vs. NWP (JP5)	
Hypothesis: True mean of the sample is equal to 512 Sample mean (LHD): 193.6	95 percent C.I.: 169.1 - 218.0 P-value < 2.2e-16

Table 31. Hypothesis test for LHD (DFM). Results: Reject the hypothesis. LHD data is not equal to the NWP.

Now we must examine the DFM fuel consumption at the operational level. The boxplots in Figure 21 show the median of HOA is much less than the other three areas. All sub-regions have IQRs that overlap. The boxplots imply if there is any difference, it would be the HOA sub-region.

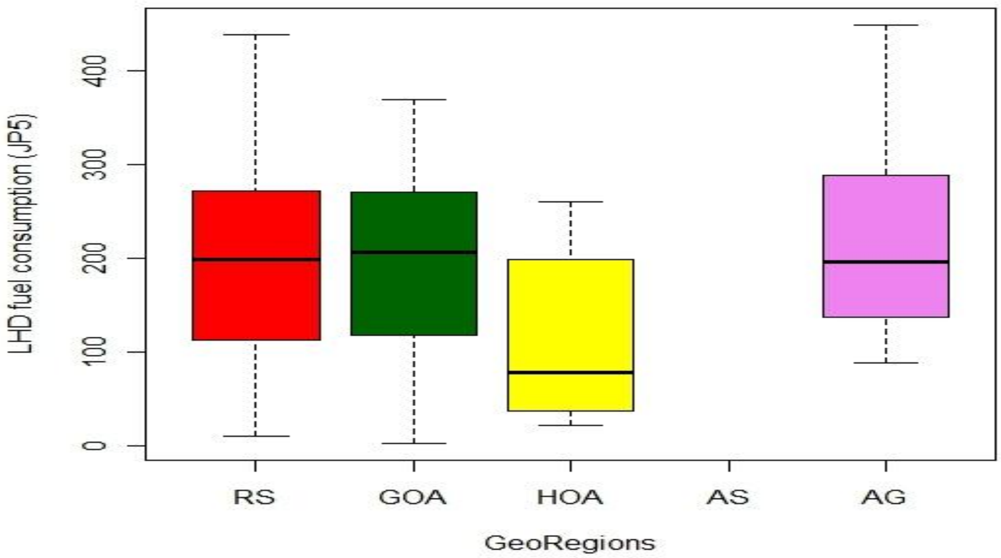

Figure 21. Side by side boxplots signifying JP5 fuel consumption. Sub-region HOA shows that the median fuel consumption rate is less than other sub-regions.

Table 32 presents the ANOVA results, indicating a large p-value (highlighted in yellow). This demonstrates there is no significant difference between one or more of the means. The data for all sub-regions will be pooled, since there is no statistical difference among them, to create one subset. This subset will be compared to the fuel consumption rate in RASP. The comparison will be completed using a hypothesis test.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GeoRegion	3	47432	15811	1.4874	0.2258
Residuals	68	722831	10630		

Table 32. ANOVA results for JP5. The p-value is larger than .05 and indicates there is no significant difference between one or more of the means.

A hypothesis test was performed and Table 33 shows the p-value is less than .02. This demonstrates the need to modify the "On Station" planning factors for JP5 fuel consumption within RASP for the LHD ship-class. The analysis shows the GeoRegion planning factors are significantly different from the NWP and RASP.

Hypothesis Test: RS/GOA/HOA/AG (JP5) vs. RASP (JP5)	
Hypothesis: True mean of the sample is equal to 512 Sample mean (RS/GOA/HOA/AG): 193.6	98 percent C.I.: 164.3 - 222.8 P-value < 2.2e-16

Table 33. Hypothesis test for RS/GOA/HOA/AG (JP5). Results: Reject the hypothesis and change the RASP value. Proposed value is 194 bbls per day.

G. LPD

There was no data was available for the HOA sub-region. Therefore, we will only examine the RS, GOA, AS and AG sub-regions.

1. DFM

The population mean for DFM is 528 bbls per day (refer to Table 1). A hypothesis test is performed to determine if our sample (the collective data points from RS, GOA, AS, and AG) could have come from a population whose mean is 528. Table 34 shows it is statistically unlikely this sample came from a population whose mean is 528, since the p-value is significantly less than .05, also the C.I. indicates 528 does not fall within the range of values where we expect the population mean to reside. This hypothesis test demonstrates logistics planners referencing the NWP are incorrectly forecasting DFM fuel consumption for LPDs within FIFTHFLT.

Hypothesis Test: LPD (DFM) vs. NWP (DFM)	
Hypothesis: True mean of the sample is equal to 528 Sample mean (LPD): 368.2	95 percent C.I.: 342.9 - 393.5 P-value < 2.2e-16

Table 34. Hypothesis test for LPD (DFM). Results: Reject the hypothesis. LPD data is not equal to the NWP.

Now we must examine the DFM fuel consumption at the operational level. The boxplots in Figure 22 show the median of AS is smaller than the other three areas. GOA and HOA show considerable variability. There is no apparent overlap of the IQRs with AS and the two sub-regions RS and AG. There are only outliers associated with the AG sub-region. The boxplots imply there may be a difference between AS and the other areas.

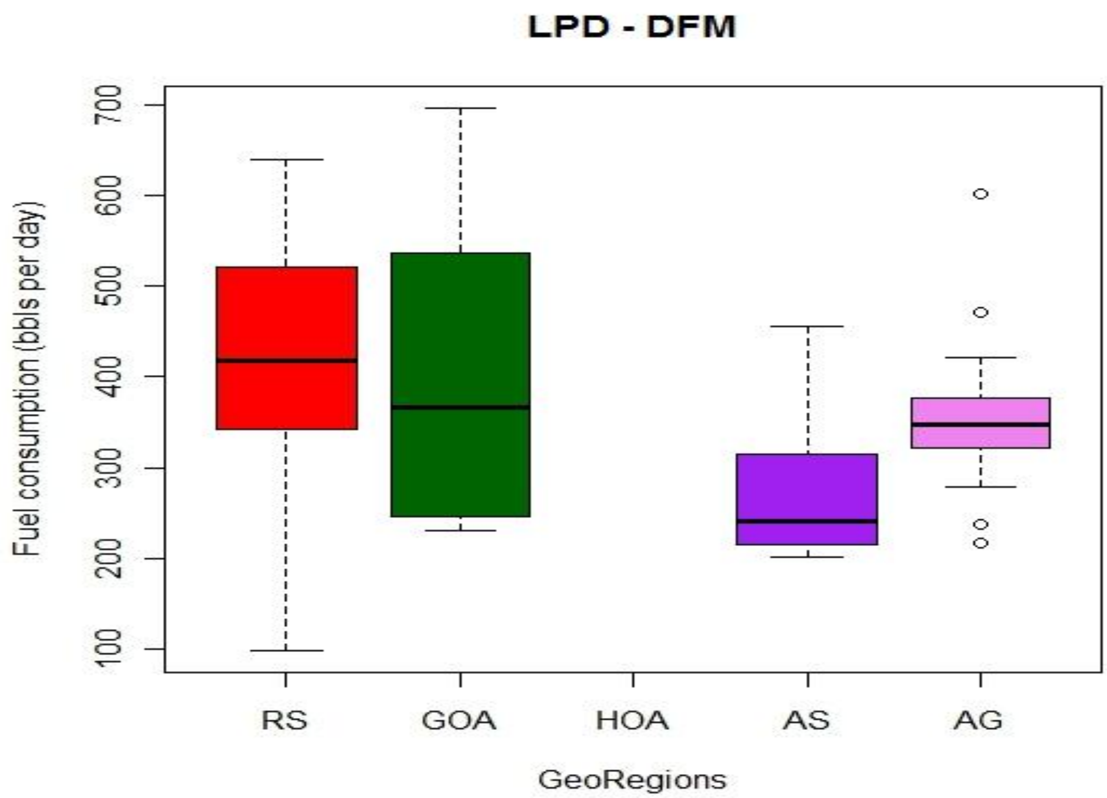

Figure 22. Side by side boxplots signifying DFM fuel consumption. The AS sub-region shows no overlap of IQR with the RS and AG sub-regions.

Table 35 presents the ANOVA results, indicating an extremely small p-value (highlighted in yellow). This demonstrates a significant difference between one or more of the means. A pair-wise comparison will be required to determine which means are significantly different.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GeoRegion	3	269871	89957	7.4211	0.0001751
Residuals	87	1054597	12122		

Table 35. ANOVA results for DFM. The p-value is very small and indicates there is a significant difference between one or more of the means.

Tukey's HSD test was performed, and Figure 23 indicates there is a significant difference between AS and two other sub-regions.

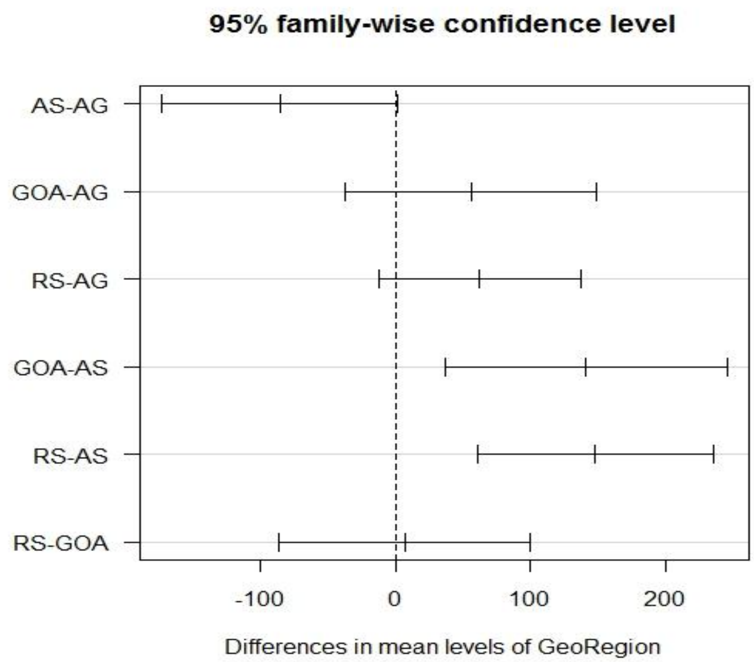

Figure 23. Tukey's HSD pair-wise comparison for DFM fuel consumption at a 95% confidence level. The plot indicates AS differs from both GOA and RS.

We will create two separate subsets based on the results of the analysis. The AS sub-region will comprise the first subset, and the pooled data of the RS, GOA and AG sub-regions will comprise the second subset. We will now compare the two subsets to the RASP model data.

A hypothesis test was performed and Tables 35 and 36 show the p-values are less than .02. This demonstrates the need to modify the "On Station" planning factors for DFM fuel consumption within RASP for the LPD ship-class. The analysis shows the GeoRegion planning factors are significantly different from the NWP and RASP.

Hypothesis Test: AS (DFM) vs. RASP (DFM)	
Hypothesis: True mean of the sample is equal to 422.4 Sample mean (AS): 261.4	98 percent C.I.: 228.9 - 293.9 P-value = 3.36e-09

Table 36. Hypothesis test for AS (DFM). Results: Reject the hypothesis and change the RASP value. Proposed value is 262 bbls per day.

Hypothesis Test: RS/GOA/AG (DFM) vs. RASP (DFM)	
Hypothesis: True mean of the sample is equal to 422.4 Sample mean (RS/GOA/AG): 388.9	98 percent C.I.: 359.2 - 418.6 P-value = 0.009008

Table 37. Hypothesis test for RS/GOA/AG (DFM). Results: Reject the hypothesis and change the RASP value. Proposed value is 389 bbls per day.

2. JP5 Fuel

The population mean for JP5 is 221 bbls per day (refer to Table 1). A hypothesis test is performed to determine if our sample (the collective data points from RS, GOA, AS, and AG) could have come from a population whose mean is 221. Table 37 shows it is statistically unlikely this sample came from a population whose mean is 221, since the p-value is significantly less than .05, also the C.I. indicates 221 does not fall within the range of values where we expect the population mean to reside. This hypothesis test demonstrates logistics planners referencing the NWP are incorrectly forecasting JP5 fuel consumption for LPDs within FIFTHFLT.

Hypothesis Test: LPD (JP5) vs. NWP (JP5)	
Hypothesis: True mean of the sample is equal to 221 Sample mean (LPD): 21.0	95 percent C.I.: 13.3 - 28.6 P-value < 2.2e-16

Table 38. Hypothesis test for LPD (JP5). Results: Reject the hypothesis. LPD data is not equal to the NWP.

Now we must examine the JP5 fuel consumption at the operational level. The boxplots in Figure 24 show the medians of all sub-regions are relatively comparable. There are several outliers in the AS sub-region. This will affect the normality (see Appendix B, Figure 88) and a log transformation will be required. The boxplots imply the outliers in the AS sub-region may cause this area to differ from the others.

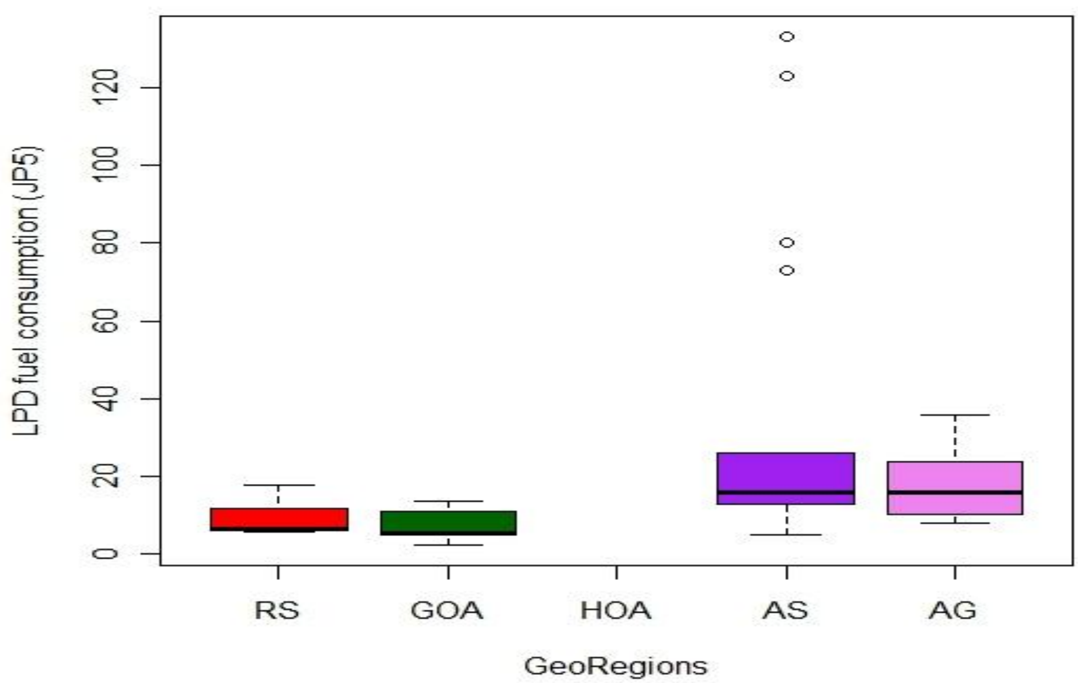

Figure 24. Side by side boxplots signifying JP5 fuel consumption. The AS sub-region shows several outliers that may cause this area to differ from the others

Table 39 presents the ANOVA results, indicating a small p-value (highlighted in yellow). This demonstrates there is a significant difference between one or more of the means. A pair-wise comparison will be required to determine which means are significantly different.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GeoRegion	3	9.8963	3.2988	6.7464	0.0007441
Residuals	45	22.0034	0.4890		

Table 39. ANOVA results for JP5. The p-value is very small and indicates there is a significant difference between one or more of the means.

Tukey's HSD test was performed, and Figure 25 indicates there is a significant difference between several sub-regions.

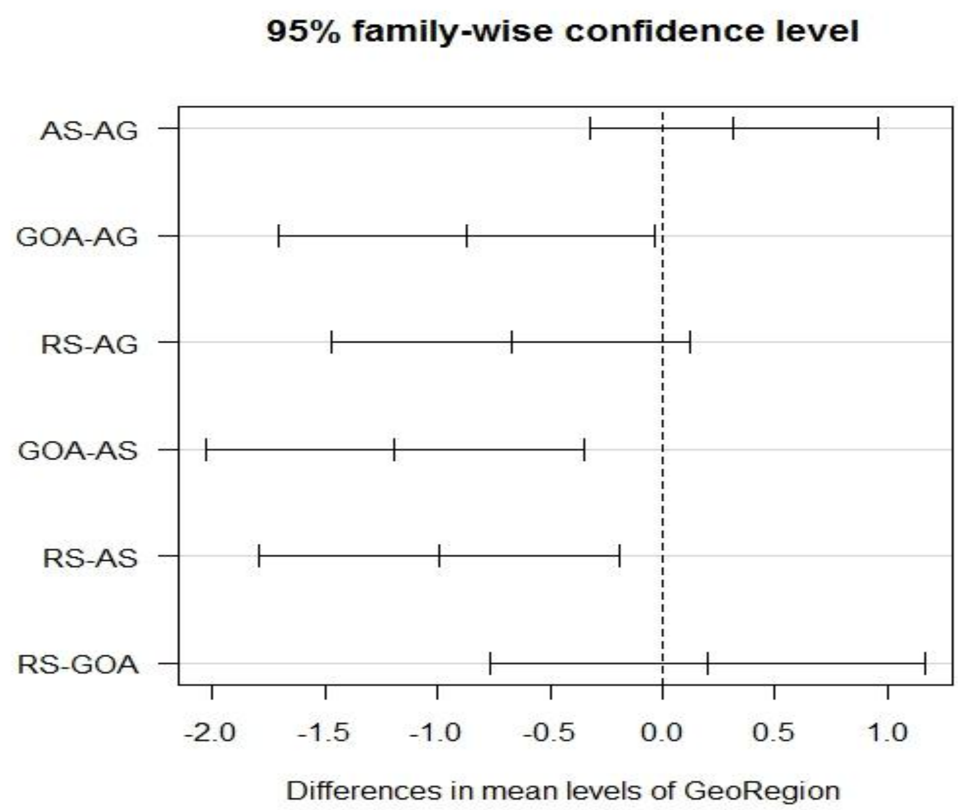

Figure 25. Tukey's HSD pair-wise comparison for JP5 fuel consumption at a 95% confidence level. The plot indicates the GOA-AG, GOA-AS and RS-AS pairs differ.

We will create three separate subsets according to the results of the pair-wise comparison. The AS sub-region will comprise the first subset, the GOA sub-region will comprise the second subset, and the pooled data of the RS and AG sub-regions will comprise the third subset. We will now compare the three subsets to the RASP model data.

A hypothesis test was performed and Tables 40–42 show the p-values are less than .02. This demonstrates the need to modify the "On Station" planning factors for DFM fuel consumption within RASP for the LPD ship-class. The analysis shows the GeoRegion planning factors are significantly different from the NWP and RASP.

Hypothesis Test: AS (JP5) vs. RASP (JP5)	
Hypothesis: True mean of the sample is equal to 221 Sample mean (AS): 35.2	98 percent C.I.: 9.6 - 60.7 P-value = 2.468e-12

Table 40. Hypothesis test for AS (JP5). Results: Reject the hypothesis and change the RASP value. Proposed value is 36 bbls per day.

Hypothesis Test: GOA (JP5) vs. RASP (JP5)	
Hypothesis: True mean of the sample is equal to 221 Sample mean (GOA): 7.6	98 percent C.I.: 2.7 - 12.5 P-value = 1.020e-11

Table 41. Hypothesis test for GOA (JP5). Results: Reject the hypothesis and change the RASP value. Proposed value is 8 bbls per day.

Hypothesis Test: RS/AG (JP5) vs. RASP (JP5)	
Hypothesis: True mean of the sample is equal to 221 Sample mean (RS/AG): 15.1	98 percent C.I.: 10.6 - 19.5 P-value < 2.2e-16

Table 42. Hypothesis test for RS/AG (JP5). Results: Reject the hypothesis and change the RASP value. Proposed value is 16 bbls per day.

H. LSD

There was no data was available for the HOA or AS sub-regions. The RS sub-region contained 10 days of data, but all the data points were classified as "no fly days." Therefore, we will only examine the RS, GOA and AG sub-regions for DFM, and the GOA and AG sub-regions for JP5.

1. DFM

The population mean for DFM is 346 bbls per day (refer to Table 1). A hypothesis test is performed to determine if our sample (the collective data points from RS, GOA, and AG) could have come from a population whose mean is 346. Table 43 shows it is statistically unlikely this sample came from a population whose mean is 346, since the p-value is significantly less than .05, also the C.I. indicates 346 does not fall within the range of values where we expect the population mean to reside. This hypothesis test demonstrates logistics planners referencing the NWP are incorrectly forecasting DFM fuel consumption for LSDs within FIFTHFLT.

Hypothesis Test: LSD (DFM) vs. NWP (DFM)	
Hypothesis: True mean of the sample is equal to 346 Sample mean (LSD): 242.9	95 percent C.I.: 223.2 - 262.6 P-value = 7.759e-16

Table 43. Hypothesis test for LSD (DFM). Results: Reject the hypothesis. LSD data is not equal to the NWP.

Now we must examine the DFM fuel consumption at the operational level. The boxplots in Figure 26 show the median of AG is smaller than the other areas. There is large variability within all sub-regions. There is overlap of the IQRs. There are only outliers associated with the GOA sub-region. The boxplots imply there may not be a discernable difference within these areas.

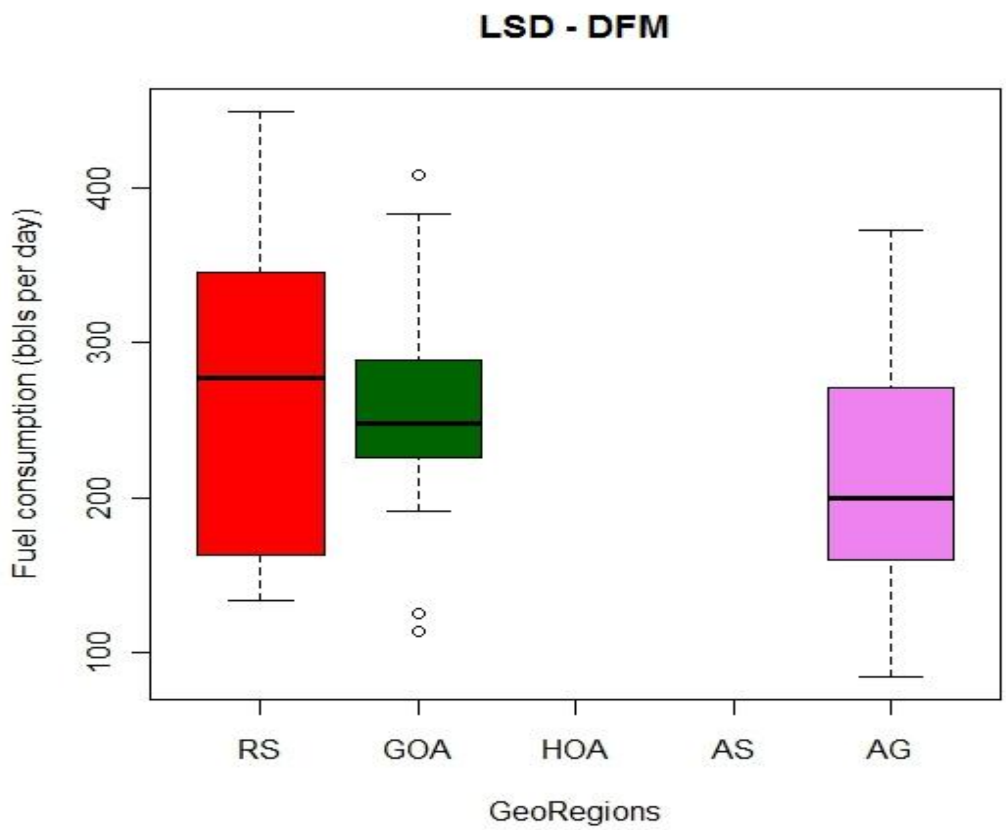

Figure 26. Side by side box plots signifying DFM fuel consumption. The chart implies no discernable differences within sub-regions.

The ANOVA was executed using the original data for this ship class. Table 44 presents the ANOVA results, indicating a p-value (highlighted in yellow) above .05. This demonstrates there is no significant difference between one or more of the means. A pair-wise comparison is not required, and we will pool all sub-regions into one subset and compare it to the RASP data.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GeoRegion	2	39417	19708.3	3.0575	0.05362
Residuals	67	431874	6445.9		

Table 44. ANOVA results for DFM. The p-value is large and indicates there is no significant difference between one or more of the means.

A hypothesis test was performed and Table 45 shows the p-value is less than .02. This demonstrates the need to modify the "On Station" planning factors for DFM fuel consumption within RASP for the LSD ship-class. The analysis shows the GeoRegion planning factors are significantly different from the NWP and RASP.

Hypothesis Test: RS/GOA/AG (JP5) vs. RASP (JP5)	
Hypothesis: True mean of the sample is equal to 346 Sample mean (RS/GOA/AG): 242.9	98 percent C.I.: 219.4 - 266.4 P-value < 2.2e-16

Table 45. Hypothesis test for RS/GOA/AG (JP5). Results: Reject the hypothesis and change the RASP value. Proposed value is 243 bbls per day.

2. JP5 Fuel

The population mean for JP5 is 55 bbls per day (refer to Table 1). A hypothesis test is performed to determine if our sample (the collective data points from GOA and AG) could have come from a population whose mean is 55. Table 46 shows it is statistically unlikely this sample came from a population whose mean is 55, since the p-value is significantly less than .05, also the C.I. indicates 55 does not fall within the range of values where we expect the population mean to reside. This hypothesis test demonstrates logistics planners referencing the NWP are incorrectly forecasting JP5 fuel consumption for LSDs within FIFTHFLT.

Hypothesis Test: LSD (JP5) vs. NWP (JP5)	
Hypothesis: True mean of the sample is equal to 55 Sample mean (LSD): 5.1	95 percent C.I.: 3.3 - 6.8 P-value < 2.2e-16

Table 46. Hypothesis test for LSD (JP5). Results: Reject the hypothesis. LSD data is not equal to the NWP.

Now we must examine the DFM fuel consumption at the operational level. The boxplots in Figure 27 show the median of AG is slightly greater than GOA. There is

large variability within the AG sub-region. There is overlap of the IQRs. There are no outliers associated with either sub-region. The boxplots imply there may no discernable difference within these areas.

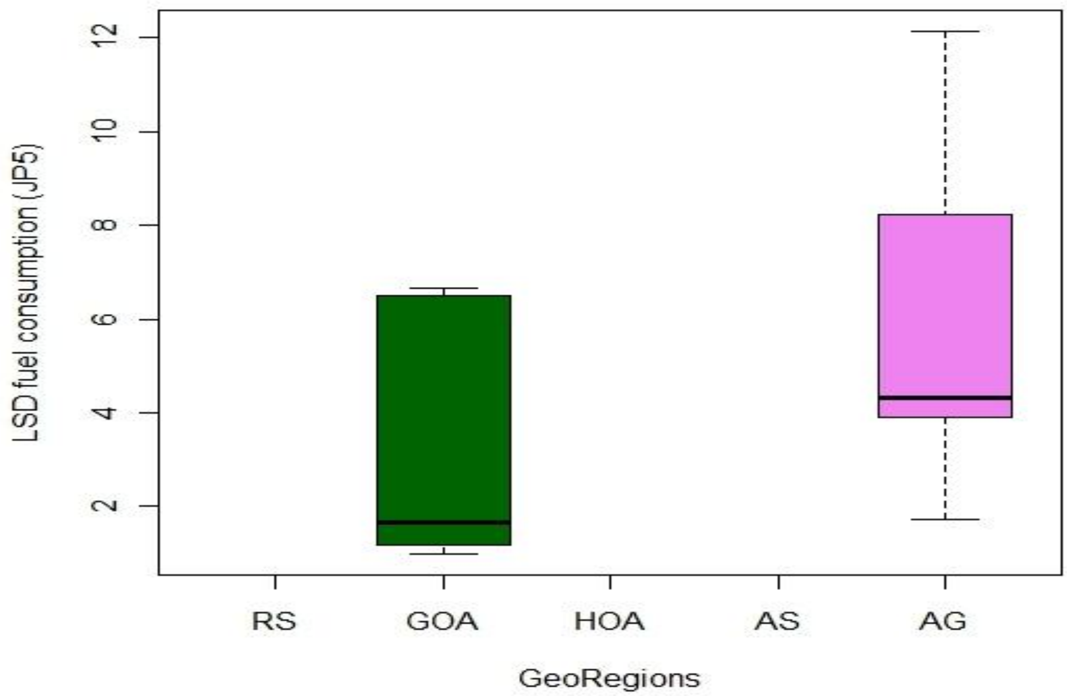

Figure 27. Side by side boxplots signifying JP5 fuel consumption. The chart implies no discernable differences within sub-regions.

The ANOVA was performed using the logarithmic data for this ship class. Table 47 presents the ANOVA results, indicating a p-value (highlighted in yellow) above .05. This demonstrates there is no significant difference between the means. Both sub-regions will be pooled into one subset and compared to the RASP data.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
GeoRegion	1	1.5338	1.53384	2.8798	0.1091
Residuals	16	8.5218	0.53262		

Table 47. ANOVA results for JP5. The p-value is large and indicates there is no significant difference between one or more of the means.

A hypothesis test was performed and Table 48 shows the p-value is less than .02. This demonstrates the need to modify the "On Station" planning factors for DFM fuel consumption within RASP for the LSD ship-class. The analysis shows the GeoRegion planning factors are significantly different from the NWP and RASP.

Hypothesis Test: GOA/AG (JP5) vs. RASP (JP5)	
Hypothesis: True mean of the sample is equal to 55 Sample mean (GOA/AG): 5.1	98 percent C.I.: 2.9 - 7.1 P-value < 2.2e-16

Table 48. Hypothesis test for GOA/AG (JP5). Results: Reject the hypothesis and change the RASP value. Proposed value is 6 bbls per day.

I. ANALYSIS USING RASP

A comparison using the "On Station" planning factors currently used within RASP and the new "GeoRegion" planning factors was modeled within RASP using a controlled 28-day scenario of actual real-world data. Figure 28 shows the 28-day DFM fuel state for 14 operationally employed naval warships. Notice in the first three weeks there are only nine incidents where the fuel state fell below the 60% safety threshold. Using the "On Station" planning factors the model determined 50 RAS (Replenishment-at-Sea) events were required.

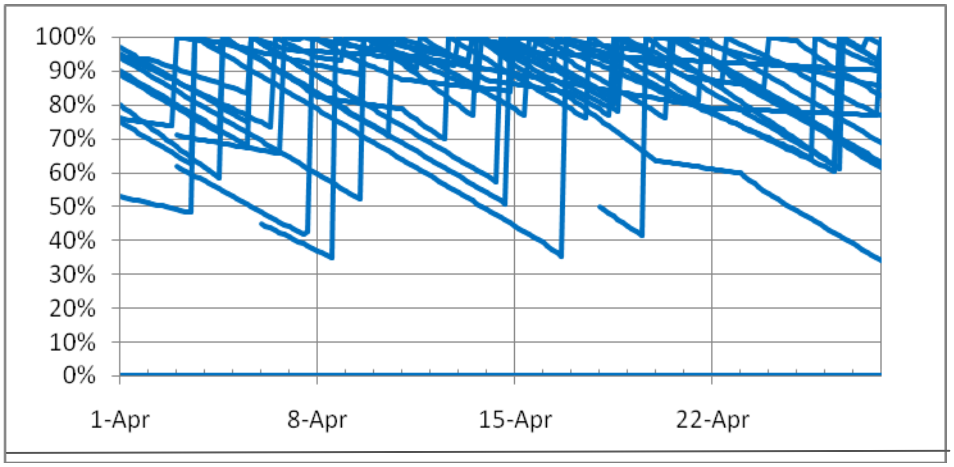

Figure 28. RASP 28 day DFM fuel state for 14 naval warships using the current "On Station" planning factors.

Figure 29 shows the 28-day DFM fuel state for 14 operationally employed naval warships using the "GeoRegion" planning factors. This also shows nine incidents where the fuel state fell below the 60% safety threshold during the first three weeks. However, using the "GeoRegion" planning factors the model determined 43 RAS (Replenishment-at-Sea) events were required. This is a net decrease of seven RAS events.

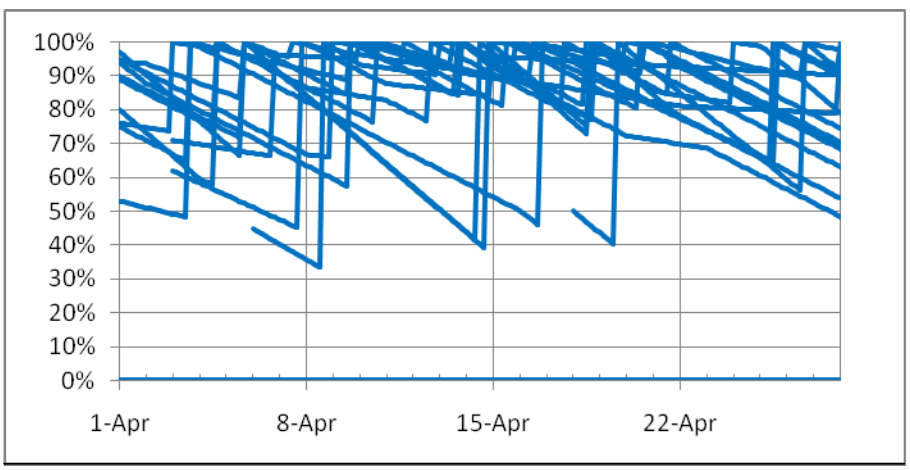

Figure 29. RASP 28-day DFM fuel state for 14 naval warships using the "GeoRegion" planning factors.

Figure 30 shows the 28-day JP5 fuel state for 14 operationally employed naval warships. Notice in the first three weeks there are nine incidents where the fuel state fell

below the 60% safety threshold. Using the "On Station" planning factors the model determined 50 RAS (Replenishment-at-Sea) events were required.

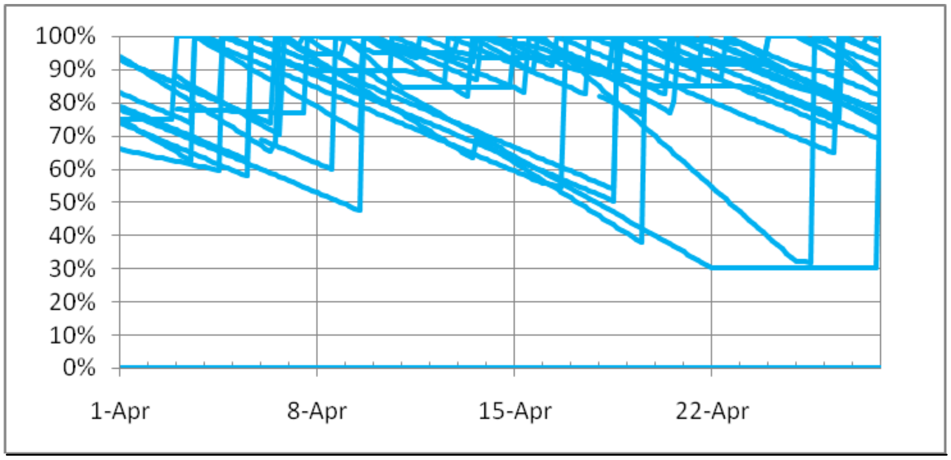

Figure 30. RASP 28 day JP5 fuel state for 14 naval warships using the current "On Station" planning factors.

Figure 31 shows the 28-day JP5 fuel state for 14 operationally employed naval warships using the "GeoRegion" planning factors. This shows eight incidents where the fuel state fell below the 60% safety threshold during the first three weeks. However, using the "GeoRegion" planning factors the model determined 45 RAS (Replenishment-at-Sea) events were required. This is a net decrease of five RAS events.

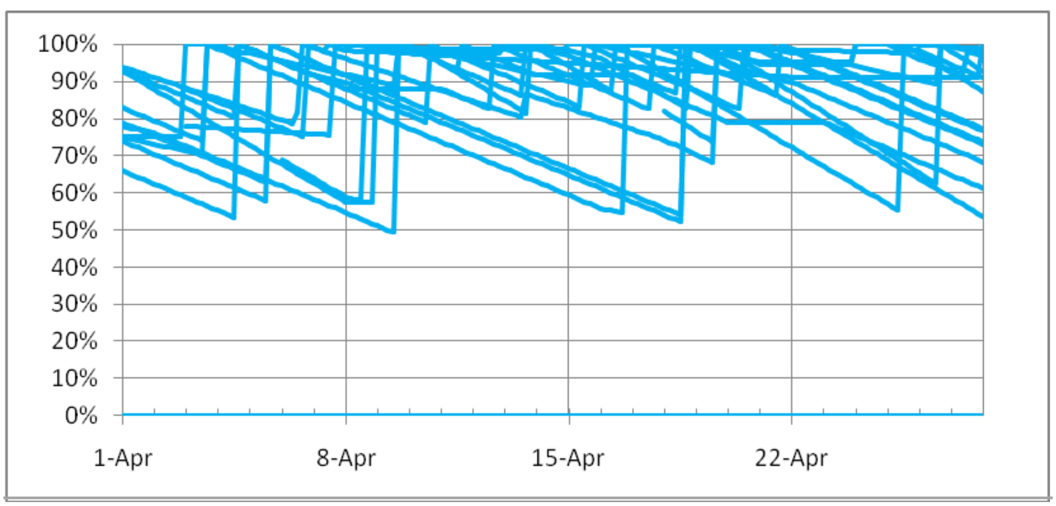

Figure 31. RASP 28-day DFM fuel state for 14 naval warships using the "GeoRegion" planning factors.

IV. CONCLUSION

A. SUMMARY

Military logistics planners should be keenly aware of the importance of precise planning factors, and their significance operational decision making. They play a crucial role in the determination of whether an operational course of action is feasible or if it is not. This analysis focused on DFM and JP5 fuel consumption within the FIFTHFLT AOR. The consumption rate of these two commodities drive a substantial portion of the operational tempo of MSC replenishment activities. Increased accuracy in the planning factors for fuel commodities assists fleet planners in forecasting the frequency and urgency of underway replenishments in FIFTHFLT.

Currently, logistics planners at the strategic level use the NWP as a guide to compose logistical plans and determine feasibility of operations. Most optimization models, such as RASP, focus on the operational level and use the NWP as a guide to develop planning factors within a specific AOR. In this case, RASP adopts the NWP "Sustainment" rate for DFM fuel consumption by a factor of 0.80, while the NWP "Sustainment' rate for JP5 is taken at face value. This study is among the first to perform an in depth validation of those strategic and operational planning factors that will potentially be used within FIFTHFLT.

This analysis has shown that both the NWP and RASP are overestimating fuel consumption within FIFTHFLT and as a result might be scheduling underway replenishment events too frequently. This data verifies that every NWP figure eclipses the actual fuel consumption within the AOR, some by as much as 600%. Tables 49 and 50 show the planning factors currently used in the NWP and RASP, as well as the proposed GeoRegion planning factors. They also summarize the proposed changes to RASP, and the rationale behind modifications of sub-regions that were not studied due to insufficient data. The stop light indicator shown beside each NWP and RASP figure indicates whether their planning factors aligns with the proposed GeoRegion planning

factors. Red indicates the figures do not match, yellow signifies some of the sub-regions match, but others do not, and green specifies that the figure is in agreement with all sub-regions.

	NWP "Sustainment"	RASP (DFM) "On Station"	Proposed Changes (DFM) RS	GOA	HOA	AS	AG
DDG	646	516.8	425	425	425	712	425
FFG	304	243.2	275	275	275	275	275
CG	757	605.6	605.6	605.6	605.6	685	494
LHD	1071	856.8	690	856.8	856.8	856.8	856.8
LPD-4	528	422.4	389	389	389	262	389
LSD	346	276.8	243	243	243	243	243
Recommend:	856.8 - Current RASP value, as well as 3/4 of the regions analyzed, and the most conservative estimator.						
Recommend:	389 - The HOA sub-region has not distinguished itself as an area of exceptional fuel consumption throughout study of the other ship classes. Expected fuel consumption should align with other sub-regions.						
Recommend:	243 - No compelling statistical evidence that HOA and AS sub-regions should differ from the other sub-regions.						

Table 49. Planning factors for DFM fuel consumption. This table shows current planning factors, as well as the proposed GeoRegion planning factors.

	NWP "Sustainment"	RASP(JP5) "On Station"	Proposed Changes (JP5)				
			RS	GOA	HOA	AS	AG
DDG	19	17	17	17	17	17	17
FFG	19	17	13	26	13	13	17
CG	19	17	24	24	24	24	24
CVN	4000	4000	3312	3312	3312	2136	3312
LHD	512	512	194	194	194	194	194
LPD4	221	221	16	8	36	36	16
LSD	55	55	6	6	40	40	6

Recommend	17 - Variability among the sub-regions lends weight to current RASP value.
Recommend:	3312 - Value presented the largest among the range of observations in this study. Maximum observed CVN consumption was 3312 bbls per day in the AS sub-region. RASP parameter of 4000 bbls per day exceeds statistical bounds. While 3312 is a conservative estimate, this study will err on the side of caution.
Recommend:	194 - Value matches other sub-regions. No compelling statistical evidence to change.
Recommend:	36 - This number matches the AS sub-region, which had the highest fuel consumption of the areas analyzed. There is no reason to believe the consumption in HOA will exceed that of the AS sub-region.
Recommend:	6/40 - The RS sub-region contained 10 days of data, however all days were "no fly days". It would be a logistical error to establish 0 bbls per day consumption rate, so this study proposes 6 bbls per day. Given a observed mean of 6 bbls per day in the other sub-regions, 55 bbls per day exceeds a reasonable estimate for the two sub-regions not studied. For HOA and AS, the the largest number of the given data points will be used. Based on observed LPD fuel consumption, this remains conservative, but this study will err on the side of caution.

Table 50. Planning factors for JP5 fuel consumption. This table shows current planning factors, as well as the proposed GeoRegion planning factors.

The new "GeoRegion" planning factors proved to be more efficient and provided a more effective optimization of RAS deliveries. There were fewer RAS events using the new planning factors, reducing JP5 hits from 50 to 45 and DFM hits from 50 to 43. Table 51 shows the number of 4-hour time periods that combatant units spent below 50% capacity.

	“On Station”	“GeoRegion”
JP5	107	3
DFM	136	71

- RASP comparison table indicating the number of 4-hour time periods combatant units spent below 50% fuel capacity.

B. FUTURE RESEARCH RECOMMENDATIONS

- Determine if RASP is using the correct “In Transit” planning factors for FIFTHFLT.
- Determine if planning factors in the NWP should be revamped, by collecting and analyzing global operational data.
- Using this thesis, determine the required number of replenishment ships needed in FIFTHFLT.
- Determine fuel requirements within FIFTHFLT for the LPD-17 SAN ANTONIO class once data is readily available
- Duplicate this analysis and verify the results using data collected after April 2011.
- Explore the fuel cost savings associated with new planning factors.

APPENDIX A

A. SUMMARY STATISTICS

1. FFG

DFM	RS	GOA	HOA	AS	AG
Mean	241.96	255.87	326.57	332.52	No Data
Median	216	223	307	340	
Range	88-455	144-477	246-445	101-543	
S.D.	96.44	87.14	76.75	119.06	
Variance	9300.55	7593.50	5890.62	14174.90	
C.I.	207.45 - 276.47	224.68 - 287.05	269.72 - 383.43	283.86 - 381.18	

Table 51. FFG summary statistics for DFM.

JP5	RS	GOA	HOA	AS	AG
Mean	13.85	25.67	10.43	6.96	No Data
Median	14.8	20	8	7.043	
Range	2.40 - 25.60	2.40 - 56.80	1.71 - 24.00	4.70 - 8.87	
S.D.	7.01	16.95	10.60	1.50	
Variance	49.15	287.44	112.41	2.25	
C.I.	11.05 - 16.66	18.88 - 32.45	.04 - 20.82	5.76 - 7.57	

Table 52. FFG summary statistics for JP5.

2. CVN

JP5	RS	GOA	HOA	AS	AG
Mean	No Data	No Data	No Data	2135.80	No Data
Median				2494	
Range				23-3312	
S.D.				832.61	
Variance				693234.51	
C.I.				1837.86 - 2433.74	

Table 53. CVN summary statistics for JP5

3. CG

DFM	RS	GOA	HOA	AS	AG
Mean	565.60	545.20	686.29	684.90	493.13
Median	584	528.5	646	649.5	451.5
Range	334-778	288-809	445-1119	372-983	297-980
S.D.	116.24	141.88	226.27	159.28	156.69
Variance	13512.27	20130.79	51199.24	25369.61	24550.88
C.I. `	493.55 - 637.65	494.43 - 595.97	518.66 - 853.91	627.90 - 741.90	437.06 - 549.20

Table 54. CG summary statistics for DFM.

JP5	RS	GOA	HOA	AS	AG
Mean	24.20	27.03	10.14	23.80	21.97
Median	21.7	21.27	10.29	25.2	21.67
Range	19.60 - 30.80	2.90 - 68.63	6.86 - 13.14	3.20 - 40.00	4.17 - 55.83
S.D.	4.29	16.68	3.18	10.54	10.84
Variance	18.43	278.36	10.10	111.10	117.47
C.I.	21.02 - 27.38	21.06 - 33.00	7.03 - 13.26	19.58 - 27.57	17.72 - 25.85

Table 55. CG summary statistics for JP5.

4. LHD

DFM	RS	GOA	HOA	AS	AG
Mean	689.04	882.33	1246.25	No Data	822.29
Median	692	860.5	1169		806
Range	333-1350	669-1391	581-2261		691-1032
S.D.	195.77	175.76	488.66		88.96
Variance	38325.26	30892.78	238784.21		7913.47
C.I. `	610.72 - 767.36	819.44 - 945.23	907.64 - 1,584.86		780.01 - 864.58

Table 56. LHD summary statistics for DFM.

JP5	RS	GOA	HOA	AS	AG
Mean	196.92	197.07	118.88		215.65
Median	198.33	205.9	77.875		195.29
Range	10.0 - 437.5	2.9 - 368.3	21.9 - 259.9	No Data	88.5 - 448.0
S.D.	113.76	100.10	97.60		96.35
Variance	12940.87	10019.43	9526.53		9283.43
C.I.	147.06 - 246.77	160.64 - 233.50	46.57 - 191.18		168.44 - 262.86

Table 57. LHD summary statistics for JP5.

5. LPD

DFM	RS	GOA	HOA	AS	AG
Mean	417.53	410.86		269.35	354.93
Median	417.5	366		241	348
Range	99-639	230-696	No Data	202-456	217-601
S.D.	121.95	176.51		67.35	70.88
Variance	14872.95	31155.67		4536.37	5023.31
C.I. `	373.89 - 461.17	318.40 - 503.32		237.34 - 301.37	329.57 - 380.30

Table 58. LPD summary statistics for DFM.

JP5	RS	GOA	HOA	AS	AG
Mean	8.97	7.64		35.18	17.90
Median	6.53	5.5		16	15.87
Range	5.60 - 17.87	2.50 - 13.50	No Data	5.00 - 133.00	7.93 - 35.70
S.D.	4.90	4.12		40.74	9.08
Variance	24.01	16.98		1659.90	82.53
C.I.	5.57 - 12.36	4.59 - 10.70		15.81 - 54.54	13.58 - 22.22

Table 59. LPD summary statistics for JP5.

6. LSD

DFM	RS	GOA	HOA	AS	AG
Mean	263.10	263.57	No Data	No Data	215.50
Median	277.5	248			200
Range	134-449	114-408			85-373
S.D.	107.79	70.03			79.89
Variance	11617.88	4904.53			6382.12
C.I.	196.29 - 329.91	238.51 - 288.63			186.91 - 244.09

Table 60. LSD summary statistics for DFM

JP5	RS	GOA	HOA	AS	AG
Mean	All Days Were No Fly Days	3.40	No Data	No Data	5.63
Median		1.67			4.33
Range		1.0 - 6.67			1.733 -12.13
S.D.		2.92			3.61
Variance		8.51			13.02
C.I.		.84 - 5.96			3.67 - 7.59

Table 61. LSD summary statistics for JP5.

APPENDIX B

A. R CODE

Read a data set in from the clipboard

```
ddg.jp5 = read.table("clipboard", sep="\t", header=T)
```

Check to see if the data correctly posted to R

```
head(ddg.jp5)
```

Attach the data frame

```
attach(ddg.jp5)
```

Create a boxplot (5 colors)

```
boxplot(ddg.jp5, xlab="GeoRegions", ylab="DDG fuel consumption (JP5)",col=(c("red","darkgreen","yellow","purple","violet")))
```

Create the logarithmic data frame

```
log.ddg.jp5 <- ddg.jp5
```

Change the data in log data frame to log numbers

```
log.ddg.jp5$RS <- log(ddg.jp5$RS); log.ddg.jp5$GOA <- log(ddg.jp5$GOA); log.ddg.jp5$HOA <- log(ddg.jp5$HOA); log.ddg.jp5$AS <- log(ddg.jp5$AS); log.ddg.jp5$AG <- log(ddg.jp5$AG)
```

Create plots in 2 rows 3 columns

```
par(mfrow=c(2,3))
```

Create qqnorm plot

```
qqnorm(ddg.jp5$RS, xlab= " ",ylab= "Fuel Consumption (bbls per day)",main="RS"); qqnorm(ddg.jp5$GOA,xlab=" ",ylab= "Fuel Consumption (bbls per day)",main="GOA"); qqnorm(ddg.jp5$HOA,xlab=" ",ylab= "Fuel Consumption (bbls per day)",main="HOA"); qqnorm(ddg.jp5$AS, xlab= " ",ylab= "Fuel Consumption (bbls per day)",main="AS"); qqnorm(ddg.jp5$AG,xlab= " ",ylab= "Fuel Consumption (bbls per day)",main="AG")
```

Create plots in 2 rows 3 columns

```
par(mfrow=c(2,3))
```

Create log qqnorm plot

```
qqnorm(log.ddg.jp5$RS,xlab=" ",ylab="Log Fuel Consumption (bbls per day)",main="RS"); qqnorm(log.ddg.jp5$GOA, xlab= " ",ylab= "Log Fuel Consumption (bbls per day)",main="GOA"); qqnorm(log.ddg.jp5$HOA, xlab= " ",ylab= "Log Fuel Consumption (bbls per day)",main="HOA"); qqnorm(log.ddg.jp5$AS, xlab= " ",ylab=
```

“Log Fuel Consumption (bbls per day)”,main=“AS”); qqnorm(log.ddg.jp5$AG,xlab= “ “,ylab= “Log Fuel Consumption (bbls per day)”,main=“AG”)

To stack the data frame (using the logarithmic data
st.log.ddg.jp5 <- stack(log.ddg.jp5)

Change the name of the stacked columns
names(st.log.ddg.jp5) <- c(“bbls”,”GeoRegion”)

Perform ANOVA on the stacked data
av.ddg.jp5 <- aov(bbls~GeoRegion, data=st.log.ddg.jp5)

Summary of ANOVA
summary(av.ddg.jp5)

Perform pairwise comparison using Tukey HSD
tk.ddg.jp5<-TukeyHSD(av.ddg.jp5)

Change the plot region size
par (mar = c(5.1, 6.1, 4.1, 2.1))

Tukey plot
plot(tk.ddg.jp5, las=1)

Read the newly created subset data in from the clipboard
sddg.jp5 = read.table(“clipboard”, sep=“\t”, header=T)

Attach the data frame
attach(sddg.jp5)

Test the samples against the true mean (adjust name to match header, ex. $AG)
t.test(sddg.jp5$AG, mu=17,conf.level=.98)

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